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CONTENTS

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INDUSTRIAL HEATING*

By Thornton Lewis†

From my own experience, I have noticed that talks of this character tend to become too technical, and, therefore, it is my intention to-night, in discussing industrial heating, to touch only the points that are of most general interest to the average engineer.

When we speak of heating a building, we really mean heating the air in that building. The carrier which is used to convey or distribute heat in a room or building is necessarily air, because air is the only gas universally present in all buildings. We cannot study comprehensively the heating of a building without at the same time giving some consideration to the amount of air entering and leaving it. The amount of air which enters and leaves a building constitutes its ventilation. It is essential, therefore, for us to consider the heating and the ventilating of a building as a part of the same problem; and, for this reason, undoubtedly, heating and ventilating are coupled together as a science and as a business. Since the two subjects are almost inseparable, it is necessary to bring into our discussion some features of ventilation in order properly to cover the subject of heating.

In this country the earliest form of heating was the open fire, built by the Indian on the ground in his tepee. At the top was an opening from which issued the smoke, and, incidentally, most of the heat. Early peoples, who lived in huts or houses, had an open fireplace in each room, with a large chimney extended above the roof. Then came the idea of using fire, encased in metal, or the stove. From this basic idea, there have been evolved all our modern heating systems of steam, hot water, hot air, etc., with their various ramifications, differences, and more or less complicated contrivances, including methods of regulation and control, all of which may be more or less necessary, depending on the exact result to be accomplished and the range of temperature allowable in each particular case.

A moment's reflection will show that this evolution has taken place in a relatively short time—a very few hundred years—so that the art or science of heating is most modern. In its short history considerable advancement has been made, particularly in the last 50

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†Vice-President, York Heating & Ventilating Corporation, Philadelphia.

years, and much greater progress may be expected in the next 50 years. This is certain because every element entering therein is now being examined basically from a scientific standpoint. Research and applied science are displacing rule-of-thumb methods.

One of the most forward steps is the establishment here in your city of the research laboratory of the American Society of Heating and Ventilating Engineers. It is operated in co-operation with the United States Bureau of Mines, and already, in its short existence, has produced some very remarkable results, including the comfort, temperature and humidity chart; the heat meter; standardized testing codes for fans, blowers and heating boilers; critical steam velocity charts, etc. The colleges and universities are also doing considerable research work along these lines, particularly Pennsylvania State College and Carnegie Institute of Technology. Last, but by no means least, many manufacturers of heating equipment have established research departments or private laboratories. There is need for all this, as the field is of great magnitude, and the application universal.

Having taken a bird's-eye view of our subject, let us get down to a more practical application. If we have to provide a heating system for an industrial building, what information is needed before we can study the details of the problem? I would list the requirements as follows:

1. The temperature desired in the building, and the minimum outside temperature experienced.

2. Complete building plans, from which may be determined the kind and amount of surfaces through which heat will be radiated to the outside, and, therefore, lost. These surfaces include the roof, walls, windows, floor, etc.

3. The amount of heat, if any, generated in the building, and from what sources, such as furnaces, or power expended by machinery or men.

4. The amount of air exhausted from the building, either by natural leakage or by mechanical means, such as fume or refuse exhaust and dust-collecting or conveying systems. Consideration should be given to any natural or existing means for replacing air thus exhausted, and whether such replacing air is at the required temperature or a temperature which is usable.

5. The primary source of heat. This would include:
   a. Waste heat from any manufacturing process.
   b. The quantity and pressure of available steam supply.
   c. The quantity and accessibility of supply of combustible gas, oil, coal or other fuel.

With the above information before us, it is possible to calculate fairly accurately the amount of heat necessary to heat a given building to any desired temperature. Having determined the quantity of heat required, the next step would be to determine the type of system to be installed.

Installations where waste heat is available are rare. A system of direct-fired heaters or stoves burning either gas, coal or oil, at various places inside the building to be heated, not only causes a very serious fire hazard, but ordinarily presents many other complications and disadvantages, such as the variable supply of heat, the high cost of maintenance, the nuisance created by smoke, dust, etc., and, except in a few special instances, high operating cost.

Hot water may be used as a circulating medium, but the first cost is high, and, further, in many ways, a hot-water system is similar to a steam system. In the large majority of cases, a steam system will be found to be the most practical, as well as the most economical in operation and first cost. I will, therefore, on account of the limited time available, confine this discussion to steam systems.

There are three types of steam-heating systems, which have worked out well in industrial plants, and these are as follows:

1. Direct radiation.
2. Central fan or blower.
3. Unit heater.

In a direct-radiation system, heating surface in the form of cast-iron radiation or pipe coils in relatively small groups, is disposed at a number of places around the building, particularly under the windows along outside walls, and occasionally overhead, where skylights or monitor sash are used. The individual radiators are supplied with steam by a main distributing system, and the condensation removed in the same way. The theory of this type of system is that the air surrounding the radiator will become heated, and, due to its higher temperature, and consequent lower specific gravity, cause a mild circulation of air to be set up in the immediate vicinity of the radiator.

By having the radiators well distributed around the building, and near the surfaces through which heat is lost, an even temperature may be maintained. A transmission factor of from 1.3 to 1.8 may be obtained in this radiation. This means that with a steam pressure of five pounds an average of 250 B.t.u. per hour per square foot of surface can be obtained.

In a central fan or blower system, heating surface of cast-iron or pipe coils is all located in one bank, which is incased, and a power-driven fan is used to draw or blow the air over the radiating surface, after which the heated air is distributed throughout the building by ducts or pipes, generally of galvanized sheet metal. Steam is brought directly to the bank of coils, and an elaborate steam-distributing system eliminated. On account of the fan being capable of moving the air against a reasonable resistance, the velocity of the air passing over the heating surface can be made as high as 800 to 1400 feet per minute without undue expenditure of power. Since it has been conclusively demonstrated that the rate of transfer of heat from saturated steam or water to air is directly proportionate to the resistance of the air passing over the heating surface, it naturally follows that a high transmission factor can be obtained with this type of system, and, as a consequence, the amount of heating surface necessary is considerably reduced, the factor being from 6.8 to 9.8, depending on the velocity used. This means, with a steam pressure of five pounds, an average of 1400 B.t.u. per hour per square foot of surface.

The unit heater system is similar to the fan or blower system in that each unit contains a bank of heating surface and a power-driven fan, all of which is self-contained. One or more units may be used, as desired or required. Unlike the central-blower system, no ducts or distributing pipes are used, but the air is discharged directly into the building through one or more short nozzles or outlets. On account of the omission of the duct-distributing system, the duct resistance is eliminated, and all the static pressure produced by the fan can be used to draw the air over the heating surface. This allows even higher velocities over this surface than in the fan system, and, therefore, secures a higher transmission factor. This is about 8 to 12, or an average of 1700 B.t.u. per hour per square foot of surface with five pounds of steam. The magnitude of the steam-distributing system will depend

on the number and size of units used, but in any case will be less complicated and less costly than that required with direct radiation.

Having briefly sketched the characteristics of the three types of systems, let us consider where each should be used. For convenience, let us rate their desirability in the order of 1, 2 and 3, to show wherein each meets the following requirements:

TABLE I. COMPARISON OF STEAM-HEATING SYSTEMS

	Direct radiation	Central blower	Unit heater
Operating cost:			
Power requirements for air movement, minimum cost	1	3	2
Steam consumption, minimum cost	3	2	1
Maintenance, minimum cost	3	2	1
Ease of regulation, minimum cost	2	3	1
Total minimum cost of operation	2	3	1
First cost:			
Material cost, minimum	2	3	1
Installation cost, minimum	3	2	1
Space requirements, minimum	2	3	1
Ratio of second-hand value to first cost, maximum	3	2	1
Total initial cost, minimum	3	2	1
Adaptability:			
Plant extension and changes	3	2	1
Large open buildings	3	2	1
Buildings divided into small rooms	1	2	3
Large rooms, different temperatures	2	3	1
Small rooms, different temperatures	1	2	3
High buildings	3	2	1
Low buildings	2	3	1
Ventilation and air conditioning:			
Outside air used	3	1	2
Recirculated air	3	2	1
Minimum temperature variation	2	3	1
Summary:			
Total first ratings	3	1	16
Total second ratings	7	11	2
Total third ratings	10	8	2
Total	20	20	20

The ratings given in the above table are based on the average industrial plant, in which buildings are not smaller than 40 by 80 feet, and have the average amount of heat loss; and where the temperature difference between the outside temperature and the desired building temperature is 50 degrees F., or more. In drawing conclusions from this table, it should be remembered that each requirement listed is not necessarily of equal value, for certainly operating cost and initial cost are generally considered the most important where heating only is the result desired.

From the above, it can be readily seen that the unit heater system is, for most industrial plants, the most desirable when all factors are considered. Since this system is the latest to be developed, and, therefore, is the least known, it will probably be interesting to discuss it somewhat in detail.

When unit heaters are used to draw air from the outside and discharge it into a building, they are serving a twofold purpose: (1) to heat the building; (2) to ventilate it. In order not to wander too far away from our subject, I will only mention this arrangement and pass on to the installation where the units are used for heating only, and, therefore, recirculate the air. In this case the theory of the unit heater system is to cause a mild circulation of the air in the building to be set up by passing a portion of it through the unit, or units, in such a way as to cause a high rate of transfer of heat from the steam to the air. While there are a number of types of unit heaters on the market, it is self-evident that the one which takes into the unit the coldest air and maintains the most even temperature will heat the building with the least consumption of steam. The vertical unit does this, as the air is drawn into it at, or near, the floor line, and usually discharged in a horizontal direction approximately 10 feet above. The vertical unit possesses another very marked advantage; namely, a saving in power. This is due to the aspirating effect obtained, making it unnecessary to operate a fan in mild weather. Except in extreme weather, it is only necessary to run all the units for a few hours in the morning in order to warm the building thoroughly, and then the power can be shut off on a few or all units and the circulation thus started will continue, even though at a slower rate, due to the aspirating effect obtained. This generation of heat at a slower rate is generally all that is required during the middle of the day, as the outside temperature usually rises during these hours. If necessary, the units may again be started near the end of the day and operated as long as the heat is required.

With a direct-radiation system in an industrial plant, the steam is generally turned on in the morning, and left on all day, regardless of the temperature outside; and, as it is expensive to install automatic temperature control, it is seldom used. With a unit heater system, it seems there is a different effect on the operating department. It is easier to realize the waste of power (due perhaps to the motor being in

operation) and, therefore, less overheating results, with its consequent waste of steam. If automatic control is used, it is easier and less costly to install on units than on direct radiation.

This last statement is also true of a blower system, but a blower system must run continuously if it is to produce any appreciable amount of heat, and so the power cost is a constant charge during the heating season. This is, to a more or less extent, true of horizontal-type unit heaters. When the horizontal type of heater is used, it is ordinarily due to the owner desiring to save floor space, and, for the same reason, vertical units are at times suspended from building columns or roof trusses. In most cases, such owners are "penny wise and pound foolish." For each square foot of floor space so saved, the owner uses approximately one-eighth to one-half of a ton of coal more per heating season. This increased cost of fuel is due to the necessity of overheating the upper part of the building in order to heat near the floor line. This is always the case where the heating surface is placed high up, regardless of whether the system be direct radiation or the unit heater.

Let us not overlook another factor in cost of operation of heating systems—that is the saving in steam that may be secured by not overheating the air near the surfaces which radiate heat to the outside.

Unit heaters may be belted to line-shafts, driven by steam-turbines or electric motors. Due to poor economy of small steam-turbines at moderate speeds, and relative high first cost, they will seldom be found desirable.

The electric-motor drive is almost universally used in this work. While the direct-connected drive is some greater in first cost than the belted, when we consider the cost and upkeep of belt and belt guard, the total cost for the life of the unit will be no more.

Unit heaters may be so located in the building that they will distribute the heat and cause the required circulation at a distance of 75 to 100 feet from the unit in each direction. The most desirable arrangement is for the units to stand on the floor in the center of the building, and blow toward the outside cold surfaces.

In conclusion, let me say that each building to be heated presents a problem which should be studied with all the factors at hand. The road to "Easy Street" in heating, as in all other problems in life, leads nowhere.

DISCUSSION

Mr. H. P. Smith:* Turbines require little attention, and should have an advantage over engines equal to the advantage of motors over engines. Although the cost of turbines is high, the cost of steam properly chargeable against the fan turbine is negligible, so the total operating cost of turbines should compare favorably with motors. The large quantities of steam used by the heating units should be sufficient to drive the fans by means of inexpensive turbines, even though the efficiency of the turbine is low.

The speed of the fan will lower as the quantity of heat needed becomes less, and the amount of power will decrease. The steam pressure used must be low if there is not enough power to drive the turbine during periods of low heating requirements. What steam pressure is ordinarily used?

Mr. Thornton Lewis: There is no reason why a turbine could not be used, but fans in heating systems are pretty low speed, under 1500 r.p.m., and not many turbines run that slowly. They could be geared down, and there is no reason why they could not be used; but they are pretty expensive—much more so than engines or motors.

I investigated the question of turbines for unit heater work and it seemed to be an ideal application. I was unable to find a turbine which would not take a good deal more steam than was required by the unit heater when 50 per cent. of its capacity was in service. In other words, if you are going to depend on the turbine to drive the unit heater you must remember that that unit heater will sometimes not be operating up to maximum capacity, and then what will be done with the excess steam? As a matter of fact, the turbines which I was able to find on the market for that work would have taken much more steam than the unit heater consumed, due to the fact that the unit heater runs at a low speed. For a small unit at 1150 r.p.m. you need three horse-power. You can see that that is an unsatisfactory turbine application. The steam runs up to 300 or 400 pounds per horse-power.

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In heating, even with high-pressure boilers, you get around 80 to 100 pounds—quite often 60 or 40. The modern tendency I find is this: that in an industrial plant they buy power from a central station, and about 50 per cent. of the plants we run into have high-pressure steam (60 to 150 pounds) for process work. Therefore, in considering a heating system, they can use a unit heater or a blower system, put high-pressure steam right in the coils, use no reducing valves, and cut down considerably the cost of the heating system. If they had to generate steam power purely for heating it would pay to put in low-pressure boilers. There is no reason in the world why turbines could not be used with high-pressure steam if you could get them to operate at the speeds and have economies that come within the capacities of the condensing surface in the heater.

Mr. P. A. Young:* I would like to know what arguments the speaker uses when a customer complains about the noise. I have known of installations where they have continually complained of the noise due to air going through the coils.

Mr. Thornton Lewis: Of course there should be no mechanical noise. If there is, something is wrong with the unit; but there is an air hum due to the high velocity of the air as it passes over the fan blades. In the only experiences I have had in cases of that character the rest of the machinery in the plant made more noise than the unit heaters, but I can conceive of places where the noise would be objectionable. Then the only thing to do is to put in large heaters and run them slowly. The question came up in one installation. They spoke of the noise, and I said, "Let us put in the equipment first and then if you have a complaint on the noise we will take it up." I have not heard anything of it since. If you have a lathe or drill-press or almost anything operating in a plant it generally makes more noise than the unit heater. If you must have absolutely silent operation there is only one thing to do, and that is to put in large units and run them slowly. The noise is usually noticed before the machinery is put in the plant. I know of only one case where that was a big consideration. I was in this plant and some motors running other machinery were screeching, as they do now and then, and they made about five

*Mechanical Engineer, Duquesne Light Co., Pittsburgh.

times as much noise as the unit heaters ever made; but noise was a consideration, so they spent the money to put in the larger units at lower speed and they were absolutely noiseless—you could not hear them when standing right beside them. For the average industrial installation, however, where you have all sorts of noises from machinery you might as well save the money and put in a unit heater running at maximum speed and get all the heat you can out of it.

MR. E. C. BRANDT:* What would be the effect if the unit heater were provided with a type of outlet on top, something similar to the shape of an umbrella instead of just a straight spout outlet? Don't you get a more uniform distribution and eliminate direct air current?

MR. THORNTON LEWIS: You would get, ordinarily, less velocity and therefore you would drive the air a lesser distance. The theory of unit heating, in large spaces, is to use the heated air as a medium to start the air in the plant circulating, and a fairly high velocity is needed to do that. Now, if you put on an umbrella outlet and do away with the nozzle effect, you have a more gradual reduction of the fan outlet velocity and less of the ejector effect.

MR. E. C. BRANDT: Don't you get direct air-current channels which create a draft from an ordinary spout outlet that seems to act like a nozzle?

MR. THORNTON LEWIS: I can only say that from my experience with a nozzle of average size, we do not. In order to make a test of that, I walked straight out from a unit and held a handkerchief out to catch the current, and when I was 75 feet away was the first time it fluttered the handkerchief. The warm air gradually came down to six feet above the floor about 75 feet away from the unit. There was no draft noticeable below six feet anywhere else but there, and then you could barely notice that there was some velocity. There was nothing objectionable about it.

MR. E. C. BRANDT: My recollection is that about 60 feet from the blower with the spout or nozzle outfit is where the people might

*Works Manager, Homewood Works, Westinghouse Electric & Mfg. Co., Pittsburgh.

catch cold by getting in the draft or channel currents. I have had this experience.

Mr. Thornton Lewis: That may have been the fault of the installation. The air outlet should be 8 to 12 feet from the floor. The objectionable velocity is eliminated by the time you get down to the six-foot level.

Mr. E. C. Brandt: You can put a damper in the spout outlet, and this has a tendency to break the draft currents.

Mr. Thornton Lewis: Yes, but if you want a distribution over a large area you have to have the velocity.

Mr. E. C. Brandt: I should imagine your fan blades would change that and would also have a tendency to change the air outlet velocity.

Mr. Thornton Lewis: If you have a certain area of outlet and move a certain quantity of air through it, that determines the velocity. The shape of the fan blade has no effect on it. If you have a certain number of cubic feet going out a certain size outlet, no matter what produces it you will have a certain velocity. With 10,000 cubic feet a minute through an outlet of five square feet, the velocity will be 2000 feet per minute and the change of the fan blade will not vary that. The change of the fan blade might vary the capacity, but it will not have any effect upon the velocity except as it varies the capacity.

Mr. A. T. Ruttencutter:* Mr. Lewis, would you say a word about the application of electric heat to the enclosed, or unit, heater and the possibility of reducing first costs, saving in transmission losses, etc., where power costs are below three-fourths of a cent? The title of your paper is so general that perhaps some mention should be made of industrial electric heating.

Mr. Thornton Lewis: I think that is something that is coming. The only places I know of where that has been used have

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been in transformer stations and substations that belong to the electric companies where they charge themselves with power at a rate lower than that which they charge the consumer. Undoubtedly, if the cost of electric current comes down and the cost of coal goes up as it is going, there will be a tremendous field for electric unit heating. If you can get water-power generating electricity at a low enough price, it is a fine thing now. I can not imagine anything more nearly ideal than that, but the thing that holds it back is the cost of power.

MR. A. E. BLAKE:* How do the unit heaters lend themselves to air conditioning such as called for in tobacco and textile factories where a certain relative humidity is essential for the desired quality of product?

MR. THORNTON LEWIS: That is one of the applications that is interesting a good many people to-day. From what I have observed, the whole tendency in all air work is toward smaller units. The old pendulum in every business swings one way and then the other. For a while it swung towards the large central system. People have become tired of constructing tremendous ducts to carry air from one central unit to wherever they want to use it; so the tendency now is to use several small units. There have been, so far as I know, no units on the market that exactly duplicate the big central humidification system. There is a big call to-day for the unit humidifier. Manufacturers are just starting to put it on the market, but I think it is coming very quickly and you will see the big central humidifying systems abolished. With small units, it would be much easier to regulate both temperature and humidity.

MR. D. C. WILLIAMS:† I should like to ask if there is any difference in the efficiency of drawing the air or pushing it through. Some of those units are of one kind and some of the other.

MR. THORNTON LEWIS: There is no difference in the actual power expended on the air passing from one side of the coil to the other, whether you draw it or blow it. The only difference is this: Wherever you change velocities you lose power—a small amount with

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†Mechanical Engineer, National Works, National Tube Co., Pittsburgh.

a slight change, but you lose some. When you start a unit, you start the air from rest and gradually increase the velocity as it enters the unit at the bottom. If the fan is at the bottom, it draws the air into the fan, making a sudden increase from the velocity at which the air is moving toward the unit to get it in the fan inlet, and reaches the highest velocity at the fan outlet. At that velocity it is not feasible to send the air through the coils. The free area of the coils is greater than the area of the fan outlet, so a drop in velocity occurs as the air enters the coil, and to get it out the outlet it must be raised again. Those changes in velocity cause losses. A gradual increase accomplished the same result with less change in velocity, and therefore with less loss of power. However, it does not amount to much—about 10 per cent. of the power. But there is no difference in the resistance of the coil itself whether you blow or draw the air through.

MR. D. C. WILLIAMS: Is there any advantage in variable speed for fan and motor and variable temperature raising or lowering the steam pressure?

MR. THORNTON LEWIS: The variation of the amount of heat which the unit gives can be accommodated to the variation in outside temperature in several ways. One would be to vary the speed of the fan. Another would be to let the fan run all the time and control, not the steam pressure (that could be done, but is not practicable), but the amount of steam given the unit. A variable-speed motor is expensive. The control of it to meet that situation is expensive. A variable-speed, alternating-current motor is difficult to get, also. It is therefore better to control it in another way. The ideal control of a unit heater is one which will shut off the power first, and then in a secondary step reduce the amount of steam that goes to the unit. The control will have to work the other way, too; that is, first open the steam valve until it gives the unit all the steam it can condense without the fan running, and then start the fan to secure the maximum amount of heat. Usually we do not put in any control. Most owners use a hand-operated switch. In the morning the unit is started and run until the plant is warmed up, and then shut down when necessary. That is the easiest thing to do, and that is what is generally done.

MR. JOHN A. GRAHAM:* Have you ever installed unit heaters in forced-circulation hot-water systems?

MR. THORNTON LEWIS: I have not, but there is no reason why it could not be done, and there is no reason why most of the heaters on the market will not work with hot water. You will not get anything like the B.t.u. per unit with the hot water, because with water entering at about 200 degrees and cooled down to 100 degrees (which is pretty low), you get out 100 heat units for every pound of water you put through. For every pound of steam you put through you get the latent heat, about 970 heat units. You have to have so much more equipment to get the same heat if hot water is used.

MR. JOHN A. GRAHAM: Would a unit heater in each corner of a large gymnasium give satisfactory heat distribution?

MR. THORNTON LEWIS: Units seem to be an ideal proposition for gymnasium heating, though I do not recommend unit heaters for churches and points where you want silent operation. You have to put in a big fan operating at low speed and low outlet velocity in order not to make any noise. With a gymnasium, a little hum does not make any difference one way or the other.

There is one thing to remember about horizontal installations. If you put in horizontal heaters you will overheat the upper part of the building in order to heat the lower part. You do not encounter this difficulty with the vertical type of heater.

MR. W. M. AUSTIN:† This description of the unit heater is very interesting and I believe a crude application very similar to it was made quite a good many years ago in places where they had direct radiation. In very cold weather they put electric fans down beside the radiator and then they had a unit heater.

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ROCK DUSTING OF BITUMINOUS COAL-MINES*

By Thomas G. Fear†

In the year 1922, eleven major coal-mine explosions in the United States killed 264 men, in 1923 five major explosions killed 265 men, and in the first 10 months of 1924 eight major explosions have killed 445 men.

No data are at hand as to the amount of sprinkling or humidification work carried on in these mines where major explosions have occurred in the past three years, but the fact that there has been an increase in the number of men killed shows plainly that the preventive measures taken have not been efficient. Considering the fact that there have been no major explosions in any rock-dusted mine in England, it is quite natural that the mine operators of this country should turn to this method of preventing coal-dust explosions.

The purpose of rock dusting is to place upon the surfaces of the underground workings a finely divided inert dust which, when placed in suspension in the air by an explosion of gas or coal-dust will extinguish and prevent further propagation of the flame. The low explosive limit of a mixture of coal-dust and air is 0.03 of an ounce of pulverized bituminous coal suspended in one cubic foot of air, and a heading 6 by 12 feet requires only 2.16 ounces of coal-dust per lineal foot to make that heading dangerous.

Coal-dust explosions may be caused by blown-out shots and, after all the precautionary means of preventing blown-out shots have been exercised, the use of rock-dust stemming should be considered. In charging holes for blasting coal the explosive is placed in the hole and the rock-dust cartridges are pushed loosely against the explosive. The dust cartridges should be ¼ to ½ inch less in diameter than the shot hole and should be filled with finely pulverized inert dust. The air space and the compression of the rock dust cushion the shot, producing a larger percentage of lump coal, decreasing the amount of explosive required, decreasing the smoke from the shot, and placing the rock dust in suspension ready to extinguish any flame which might be caused by the explosive. The effect of this dust on the quality of the

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coal has been questioned by a number of coal operators, and a few figures will show that the increase in the ash content is negligible. In a room producing 30 tons per cut, three holes are fired with 4.5 pounds of rock dust per hole and the increase in the ash content will be 0.02 of one per cent.

The ignition hazard due to ignition of methane gas can be materially reduced by the proper supervision of the mine; the use of electric cap lamps and magnetically locked safety lamps; firing all shots by electric detonators; the use of permissible explosives; the proper ventilation of the mine, and frequent testing of all return air to determine the percentage of methane gas; the use of flame-proof electric motors or air-operated motors where the methane content of the mine air cannot be kept low; the fusing (at the power end) of all electric cables on mining machines, cable-reel locomotives and other portable electrically operated machines; and the proper insulation and constant supervision of all electric wires. One hazard which might be mentioned is the extension of trolley wires and other conductors too close to the slope bottom, where runaway trips on the slope may tear down the wires causing an electric arc and ignite the coal-dust placed in suspension by the wrecking of the cars. This dust can not be treated and the hazard must be removed by the elimination of the wires.

At present, there are three different methods of treating dust in a coal-mine to render it explosion proof — sprinkling, humidification process, and rock dusting.

Sprinkling and spraying water on coal-dust has been practiced by many coal companies for a number of years, and in many instances has prevented serious dust explosions. The difficulty of properly wetting coal-dust and the uncertainty of the moisture content due to the variable relative humidity of the mine air, are the principal defects of this system. The cost of efficient sprinkling is high—one coal company in Alabama employs 16 sprinklers daily at a mine with a daily tonnage of 2400 tons; another company operating three mines, with a total daily tonnage of less than 6000, employs 45 sprinklers.

The humidification system preheats the air entering the mine and loads it to capacity with water to simulate conditions which usually prevail during the summer months. This system requires expensive alterations and additions to the ventilating system and an expensive

heating plant. The practicability of this system in climates where the temperature drops as low as 10 to 20 degrees below zero Fahrenheit may also be questioned on account of the damage done to the roof by the excess moisture and the creation of fogs along the main haulage-way and other working places.

The latest method to be employed in the mines of this country is the use of rock dust either in barriers or distributed over the surfaces of the underground workings. Barriers may consist of a series of shelves or troughs filled with rock dust and so suspended that the dust will be placed in the air by an increase in the velocity of the air current.

The United States Bureau of Mines has defined coal-dust as all such particles of coal as will pass through a 20-mesh screen. Particles over this size do not ignite under ordinary conditions and may be disregarded. All coals, with the exception of anthracite, make explosive dust, and a very complete report on coal-dust may be found in United States Bureau of Mines Bulletin 50. Rock dust for dusting coal-mines as recommended by the United States Bureau of Mines is a powdered mineral with less than two per cent. combustible material, all of which will pass through a 20-mesh screen and 50 per cent. through a 200-mesh screen; to be free, or practically so, from silicious particles; and as light in color as possible, to permit of visual inspection and to increase the illumination of the haulage-ways. Limestone dust fulfils all these requirements and should be used whenever available at a reasonable cost. Where these ideal dust specifications can not be met, rock dust with a higher silica content may be used without any great injury to the workmen.

In the examination of the Indianola mine of the Inland Collieries Company to ascertain the coal-dust hazard and to determine the amount of rock dust necessary to render the coal-dust explosion proof, samples were taken at frequent intervals along the headings. The dust through a 20-mesh screen in 70 samples ran from zero to 3.1 pounds per lineal foot of heading. The larger samples were taken on haulage-ways and contained from 30 to 50 per cent. of sand. The coal-dust on the ribs, roof, and timbers was practically all air-floated material and was therefore the finest and most explosive dust. One sample taken from the top of a timber tested 83.5 per cent. through a 200-mesh screen. From the maps and records it was found that there

were 11.65 miles of haulage entries, 33.3 miles of air and traveling ways, 13.75 miles of room necks and cross-cuts and 5.46 miles of rooms. The total of narrow work or headings to be dusted was 58.7 miles.

The first machine at Indianola was operated by compressed air, and a 100-foot machine at 60 pounds pressure with a two-inch nozzle put on 80 pounds of dust per minute. Later an improved dust distributor was built, using a blower in place of the air compressor. By experiment it was found that, with a given nozzle pressure and quantity of dust, a certain distance from the nozzle to the surface to be coated gave the best results. The rock dust when blown against the surfaces of the headings dislodges most of the coal-dust and fills the crevices, etc., with rock dust which, due to its greater angle of repose, clings to the surfaces in greater quantities than the coal-dust displaced. It was also noted that most of the coal-dust blown off the timbers and ribs was deposited on the floor.

Six months after the main haulage-ways were completely rock dusted, samples were taken and tested by means of the volumeter. The percentages of incombustible material were as follows:

TABLE I. PERCENTAGE OF INCOMBUSTIBLE

Number of samples		High	Low	Average
41—Haulage	Roof and ribs	98.0	49.0	73.8
40—Haulage	Floor	90.5	47.5	72.1
6—Haulage	I-Beams	100.0	98.0	99.6
17—Airways	Roof and ribs	83.5	22.5	47.1
16—Airways	Floor	99.5	24.0	68.9
3—Airways	Roof, ribs and floor	46.0	34.0	38.7
9—Rooms	Roof and ribs	92.0	23.0	56.3
9—Rooms	Floor	77.0	29.0	57.9

In the month of May, 46,000 feet of entries were dusted and 105,400 pounds of limestone dust used, or an average of 2.3 pounds per lineal foot. The total cost of labor and material was $505.73, or $0.011 per lineal foot of entry. The limestone dust cost $4.40 a ton delivered, and $0.50 a ton was added for handling. From the reports kept at this mine during the past six months, the cost of dusting is as follows, on the basis of 4000 feet dusted per eight-hour shift,

and 8000 pounds of dust used at $4.40 a ton, plus $0.50 for handling:

Labor, two men at $7.50	$15.00
Dust, four tons, at $4.90	19.60
Power, repairs, etc	6.00
	$40.60
Cost per lineal foot	$0.01

The cost of dusting a mine producing 61,000 tons per month where 5600 feet of narrow work is driven each month will be two mills per ton when the headings are redusted twice a year, and three mills per ton when redusted four times a year.

The Pennsylvania Compensation and Rating Bureau has recognized the value of rock dusting and the report of the committee was as follows:

"Realizing that through the extensive demonstrations and experiments carried on for several years by the United States Bureau of Mines as well as the practical application of rock dusting by the different mining corporations of this country, together with what we know has been accomplished in Great Britain, this Committee is of the opinion that there is an abundance of conclusive evidence that explosions of coal-dust, with the resulting loss of life therefrom, are preventable by the proper application of rock dust, and our Committee is unanimously of the opinion that our Standard should make particular and individual recognition of the merit of rock dusting as a prevention of coal-dust explosions and that a substantial credit should be allowed in our schedule rating plan for mines in which proper rock dusting is carried on in mines where inspection indicates a coal-dust hazard."

A credit of 10 cents per $100 of payroll was agreed upon for mines complying with the following rule: All entries, air-courses, manways, room necks and entrances or approaches (other than old room necks) to old and abandoned sections shall be rock dusted with limestone, shale or other inert dust approved by the United States Bureau of Mines. The application shall be in sufficient amount and of sufficient frequency to maintain on roof, ribs, bottom and timbers and all places of lodgment, sufficient inert dust so that the combustible content of the resulting mixture of rock dust with mine dust shall not exceed 45 per cent. at all times.

In addition to the main object of rock dusting—the safety feature—there are a number of other advantages which may be mentioned here. Where limestone dust is used, the illumination is greatly increased, and this should reduce the haulage accidents and give

greater efficiency in the mine labor. Both steel and wood timbering are protected to some extent by the coating of limestone dust and the wood timbers will be partially fireproofed. Rock dust will to some extent prevent disintegration of certain mine roofs by keeping atmospheric moisture from the roof.

There can be no ill effect on the employees from rock dust, for the dust is deposited on the underground surfaces and is placed in suspension in the air only by an extraordinary velocity. The velocity of a swiftly moving train in the mine will dislodge some dust the first trip after dusting; but when this fine dust has been carried along there will be no further disturbance of the dust.

The effect of moisture during the summer months is to cake the rock dust, and a subsequent drying out during the winter months will restore the dust to about 50 per cent. of its original value. When the rock dust is moistened, it will prevent further propagation of a flame, but will not stop nor extinguish a flame. For this reason the combination of watering and rock dusting should not be attempted.

Rock dusting has come to stay in the coal-mines of this country. It is no longer an experiment, and when all the mines are rock dusted there will be no more of the so-called major explosions which have been taking such a large toll of human lives.

DISCUSSION

Mr. W. L. Affelder:* Before you used rock dust at Indianola did you sprinkle your mine with water?

Mr. Thomas G. Fear: Yes. We put in an elaborate system of piping, using an old oil-well to run the water into the mine at about 110 pounds pressure.

Mr. W. L. Affelder: Do you think your mine is dusty enough in winter time to require sprinkling?

Mr. Thomas G. Fear: Yes.

Mr. W. L. Affelder: How do you get around the Pennsylvania mining law in the matter of omitting sprinkling? What I have in mind is this—the Pennsylvania mining law, in spite of the fact that the Compensation and Rating Bureau allows a credit of 10 cents per $100 of payroll, does not recognize rock dusting.

Mr. Thomas G. Fear: It does not say that; it says sprinkling. It does not say sprinkling with water.

Mr. W. L. Affelder: I think it implies that, at least.

Mr. Thomas G. Fear: I think not.

Mr. W. L. Affelder: It states sprinkling to a certain degree of dampness of the dust. I do not think you will be able to evade the law in that way.

Mr. Thomas G. Fear: I know that in Illinois it says sprinkling, and nothing about sprinkling with water or rock dust.

Mr. W. L. Affelder: I was wondering what some of us would do if some inspector with lack of judgment should hale us into

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court for rock dusting rather than sprinkling. Our company is rock dusting in six or eight mines. We have abandoned the use of water sprinkling and are using rock dust. I wonder where we would be if some inspector should undertake to make a test case of one of our mines.

Mr. Thomas G. Fear: I do not know. I judge they would not care to take us into court.

Mr. W. L. Affelder: I thought that, too, in another case, until last week.

The trouble is that the present mining law was written in 1911 and it is obsolete in certain respects, but the fact remains that it is the law.

Mr. F. A. McDonald, *Chairman*:* That is true in several cases of improvement in methods. Technically, they are contrary to the law, in which case mining engineers and operators should use their influence to have the mining laws so amended that the improved practices become legal, and obsolete practices be eliminated.

Mr. W. L. Affelder: I raise this question because I know that Mr. J. J. Walsh, who is the Secretary of Mines of Pennsylvania, is very anxious for some of us to get together and draw up a suitable amendment to the mining law. He told me so at Harrisburg. Whether we want to do so on our own initiative, with the co-operation of the Department of Mines, is a matter we will have to decide this winter.

Mr. Thomas G. Fear: The American Institute of Mining and Metallurgical Engineers has appointed a committee, with Mr. Eavenson as chairman, and Mr. J. W. Paul representing the mine inspectors. We intend to draw up a standard practice in rock dusting and present it to the different state legislatures as a guide in making laws. Not to make the law, but to let it be a guide. Mr. Fieldner has just come back from Europe and he will know a good deal more about rock dusting than any of the rest of us.

*General Superintendent and Chief Engineer, National Mining Co., Morgan, Pa.

Mr. A. C. Fieldner:* I am impressed with the tremendous strides that have been made in the technique of rock dusting in America during the last year. It is not a year since Mr. Walker, then Deputy Chief Inspector of Mines of Great Britain, now Chief Inspector, described to the members of this Society in this room the legal requirements for rock dusting of coal-mines in Great Britain. Mr. Walker assured us that rock dusting was a practical proposition and that it would prevent the propagation of coal-dust explosions. In other lectures at the Bureau of Mines and at Carnegie Institute of Technology, Prof. Wheeler, Director of Research for the Safety in Mines Research Board of Great Britain, gave us the scientific reasons underlying the use of rock dust in preventing ignition and propagation of explosions. The author of the paper this evening went away from those meetings impressed with the idea that he could use rock dust in the mines under his supervision, using American methods, just as economically as was being done abroad (or perhaps more economically), in spite of the fact that foreign labor is very much lower priced than American. Other operators of the Pittsburgh district likewise turned their attention to rock dusting, so that the movement gathered force as it rolled along and in a period of less than a year has spread over both the eastern and western coal-mining districts.

The first night following my return to Pittsburgh from a four-month trip in Europe I accompanied Mr. Owings, of the Bureau of Mines staff, to one of the mines in the Pittsburgh district where he and Mr. Dodge, a research fellow of Carnegie Institute of Technology, are studying methods and costs of applying rock dust. In that particular mine they were using one of the new American machines. The work was being done efficiently and at a reasonably low cost. I found no rock-dust spreading machines in operation in the mines I visited in Europe. However, I was underground in a few mines only, my principal object being a study of foreign research methods on safety in mines and fuel utilization.

In England I visited the Bentley mine, in which rock dusting has been carried on for over ten years. The rock dust was ankle deep in many places. I saw one of the Oldham rock-dust spreading machines, but was informed that it was not used much. It has a fixed discharge which merely throws the rock dust into the air. In English mines they

*Superintendent, Pittsburgh Experiment Station, U. S. Bureau of Mines.

rely almost entirely on spreading the dust by hand. It is apparent that the development of mechanical methods in America is making it possible to apply rock dust at a lower cost than by the hand-labor methods in Europe.

I was particularly interested in observing the kind of rock dust used in England. In the Bentley and Kirkby mines they were using dust made from shale from the mine itself. The following are analyses of samples of each of these shales which I brought back and had analyzed in the laboratory of the Pittsburgh Station of the Bureau of Mines:

Bentley Collieries, near Donchester, England.

	Per cent.	
	As received	Moisture free
Moisture at 105 degrees C.	1.2	0.0
Ash	91.2	92.3
Carbon dioxid (CO_2)	2.8	2.8
Combined water (above 105 degrees C.)	4.0	4.0
Total incombustible	99.2	99.1
Combustible (by difference)	0.8	0.9

Free silica or quartz (SiO_2), estimated..........23 per cent.

Kirkby Colliery, Butterley Company, Nottingham, England.

	Per cent.	
	As received	Moisture free
Moisture at 105 degrees C.	0.7	0.0
Ash	93.3	94.0
Carbon dioxid (CO_2)	0.2	0.2
Combined water (above 105 degrees C.)	3.8	3.8
Total incombustible	98.0	98.0
Combustible (by difference)	2.0	2.0

Free silica or quartz (SiO_2), estimated..........27 per cent.

Though the Bentley mines have been using shale dust for over ten years, it has no ill effects on the miners. Our tentative standard for the Bureau of Mines in this country is 25 per cent. free silica, which appears to be a safe limit according to practical experience in England.

I visited Dr. Haldane, the great English authority, who has done so much research work on mine gases and effect of rock dust. He stated that he had not found any cases in England where miners were troubled with silicosis due to rock dusting. Dr. Haldane judges the quality of a shale largely by the feel of the powder when rubbed between his fingers. If it is free from gritty and sandy particles it is

considered satisfactory for rock dusting. He admits that limestone is much more desirable if it can be obtained, as there is absolutely no doubt that limestone is perfectly harmless when inhaled.

In the Bentley mine the shale is taken from above the roof coal. It is a light-colored shale. They reject the sandy and iron-bearing portions. They have recently installed regular cement-grinding tube-mills of a capacity of two tons per hour each for finely pulverizing the shale. Over 80 per cent. of the material goes through a 200-mesh screen. This new grinding machine was installed very recently and they had not had much experience with this very fine dust. The mine superintendent was of the opinion that it was too fine—that in throwing it against the walls it did not knock off the coal-dust as well as when mixed with some coarser particles. In sampling the Bentley mine they mark off a zone 50 yards long. A grab sample is taken from each square yard. These are then combined, thoroughly mixed, and quartered down. The top, side and bottom samples are kept separate. The total bulk of the gross grab sample is about a two-gallon bucketful. This is screened through a 28-mesh sieve, the oversize rejected, the undersize mixed and quartered to about 20 grams, or a little less than an ounce, which is then put into a bottle and taken out of the mine to the laboratory for determination of moisture and ash. The men doing this sampling can collect about 12 samples a day. Their method of determining incombustible by the long moisture-and-ash method is much more tedious and time consuming than the volumeter method recommended by the Bureau of Mines.

The pit shale used for rock dusting at the Kirkby Collieries felt soft to the touch and pulverized to a fine whitish-gray powder of appearance similar to limestone The free silica in this material is shown in the analysis quoted above.

In northern France in the coal fields of Pas-de-Calais and Du Nord they use chalk dust from the rock chalk formation You will recall that this chalk formation extends from this coal field to Calais, and across the English Channel, forming the white cliffs of Dover, opposite.

I was underground in the Bruay No. 6 Mine of Cie des Mines de Bruay. The coal-beds are at a depth of 1200 to 1500 feet. Over the coal-beds there is chalk about 500 feet in thickness. This chalk is easily pulverized in a disintegrator. It is spread in the entries and

roadways, and up to the working face. They would like to maintain over 70 per cent. incombustible in the dust mixture. All the dusting is done by hand. Samples are regularly taken and sent to the laboratory for test. The incombustible is determined by the volumeter method similar to that of the United States Bureau of Mines, and checks are also made with the Taffanel length-of-flame apparatus. In this apparatus one gram of the dust mixture is blown with a puff from compressed oxygen under 400 millimeters water pressure into a source of ignition. The length of flame produced is inversely proportional to the incombustible in the dust. At Bruay they determined that the flame length must not exceed 50 centimeters for non-gaseous mines and 30 centimeters for gaseous mines. However, the flame-test apparatus is not as duplicative or precise a test as the volumeter method. They sample the various entries once every three months.

In Germany I visited the coal-dust experiment station at Derni, near Dortmund. Mr. Carl Beyling, in charge of this station, visited the Pittsburgh Experiment Station about twelve years ago. He stated that rock dusting was gradually replacing watering in the German coal-mines. In England rock dusting is obligatory; in Germany they may either water the mines or rock dust them. If the mine has such conditions that it can be effectively watered (and many of them are naturally very wet), the government does not require the use of rock dust. If, however, watering is not sufficient to prevent the hazard of coal-dust explosions and propagation, rock dusting is required. Mr. Beyling and his associates are carrying on a general campaign in demonstrating the use of rock dust, rock-dust barriers, and Krauskopf cushioned blasting. Mr. Beyling stated that in the Westphalia district the mines either water profusely at the working faces, scatter stone dust in the rooms before firing, or use Krauskopf sand cushions over the mouth of the bore holes. The use of sand only in paper cartridges in the bore hole is not considered sufficiently safe, although it leads to the use of less explosive and production of more lump coal. Mr. Beyling considers stone dusting cheaper than watering, because of the cost of pipe and extra timbering required in wet mines. He says that stone-dust barriers are rapidly coming into more general use and that the Krauskopf method of cushioned blasting is being used in a number of mines. He roughly estimates that five per cent. of the Westphalia mines use this method of blasting, and that 50 per cent.

of the mines now use stone dust either as a covering over the bore holes or scattered about in a part of the mine at least. If mines do not stone dust completely they must water heavily the places that are not stone dusted. At the present time not more than 10 per cent. of the mines use water exclusively. In the Krauskopf method of cushioned blasting, about two kilograms (which would be about 4½ pounds) of stone dust is placed over the mouth of the bore hole. This dust is either in a paper bag or rests on a small triangular sheet-iron shelf that is stuck into the coal directly under the bore hole. The dust must be squarely over the mouth of the hole. Such a method presupposes that all the miners follow the instructions very carefully; and, to an American, it places too much dependence upon the human element. In general, it appeared that the German methods rely to a greater extent on regulating the human element with definite instructions and regulations than we would do in America.

Mr. Beyling stated that the miners raised some objections to the use of stone dust on the ground that it would injure their lungs. They therefore created a Physicians' Commission, consisting of Prof. Dr. Bruno Heymann, of the Hygienic Institute of the University of Berlin; Prof. Dr. Ceelen, of the Pathological Institute of the University of Berlin, and Prof. Dr. A. Bruns, of the Hygienic Institute at Gelsenkirchen. This Commission placed dogs and guinea-pigs in mines which were stone dusted. They kept them in these mines for nine months—that is, they kept the guinea-pigs; the miners took the dogs home for souvenirs before the experiments were completed. While the results are not yet published, Mr. Beyling stated that no silicosis or other deleterious effect was produced on the lungs of the guinea-pigs. The Commission is carrying on further experiments in the laboratories.

MR. N. F. HOPKINS:* How would lime do as a rock-dusting medium? There would be a greater quantity of fine material, would there not?

MR. THOMAS G. FEAR: Why do you want to use lime when you can get unburned limestone, which is cheaper and less harmful? You can get 96 per cent. through a 200-mesh screen with limestone

*Harrop & Hopkins, Pittsburgh.

dust; and I think there is a certain point beyond which the rock dust is so fine that it will cake of itself. With moisture, it will cake so hard that it will be almost useless.

Mr. W. L. Affelder: Is it not a fact that, even after it is slaked, lime has a greater affinity for water than limestone has?

Mr. Thomas G. Fear: It absorbs CO_2 from the air and hardens.

Mr. W. L. Affelder: Is there any representative here of a company which manufactures limestone dust? It would be interesting to know to what extent limestone dust is being sold at this time.

Mt. Thomas G. Fear: I think there is a man here from a limestone company. I would like to say first that this afternoon I received a letter from the representative of a company from which we have been buying limestone. He wanted to know why we did not buy any more and what happened to the operators that they suddenly stopped buying. He wanted to know whether we were giving up the idea of rock dusting, or grinding our own shale, and he wanted to know whether he should spend money for advertising or quit.

Mr. A. R. Chambers:* The question asked by Mr. Affelder regarding the interest of the coal operators on the matter of rock dusting is shown to a great extent by the number of inquiries which the Michigan Limestone & Chemical Company has received during the last five or six months. Since the meeting of the American Mining Congress, in Cincinnati last June, at which time rock dusting was discussed, we have had numerous inquiries from coal operators in Pennsylvania, West Virginia and Ohio.

I suppose we have received more inquiries from coal operators regarding this question than any other commercial company, on account of the fact that the Michigan Limestone & Chemical Company has for a long time been the leader in the limestone industry and has no doubt been the pioneer in pulverizing of limestone for agricultural and other commercial uses. The inquiries which we have

*General Agent, Michigan Limestone & Chemical Co., Pittsburgh.

received show us that rock dusting is a most vital problem with the coal operators of to-day, and we have found that where the operator does not contemplate doing this work immediately he is collecting data relative to this problem with a view of starting on a rock-dusting program after the first of the year. In letters which we have sent to the coal operators following up our first letter, we find that the majority of them consider it a very vital problem, and where plans are not made for the first of the year we have been told that they will start rock dusting as soon as business permits.

Someone this evening asked whether material other than limestone dust was being considered by the coal operator. I may say in this connection that limestone is the only material being considered generally by the coal operators for this work. The United States Bureau of Mines has designated it as a most suitable product on account of such characteristics as its color and its low content of silica. Another point of great advantage is the fact that during the past ten years there have been erected over the eastern part of the United States extensive plants for the manufacture of agricultural limestone, and the limestone interests are already equipped to handle the requirements of rock dusting.

It is true that other material has been thought of by the coal operator. One operator in the Pittsburgh district has received a sample of marble dust from Vermont, but the freight rate on such a shipment will undoubtedly make this material prohibitive in this district. I am told that the railroad people have been asked by different manufacturers, such as the brick people, to establish commodity rates for shipment of brick-dust for this work, but the feeling at the present time is that the limestone dust with its outstanding qualities, as well as the existing limestone operations, offer to the coal operator a better source of supply than in any other material.

MR. F. A. McDONALD, *Chairman*: What is your method of dusting those parts of the mine where you are not able to move your machine, as in return air courses?

MR. THOMAS G. FEAR: Knock a hole through the stopping and take a four-inch iron pipe in 10-inch sections with long-radius elbows and take that wherever you want it.

MR. J. MCCRYSTLE:* I understand that the return airways at your mine are dusted by breaking a hole in the stopping which separates the intake from the return air current, then inserting a nozzle from the rock-dust apparatus and discharging this into the return current. The dust in suspension in the ventilating current is then deposited gradually upon the roof and ribs.

Do you not think that rock-dust barriers would be preferable in main returns, particularly those remote from the active workings? It would seem to me that there are several objections to dusting the return airway from the adjoining entry:

1. Short circuiting of the air current due to leakage through stoppings is always a source of trouble in ventilation, and any system that calls for tampering with the stoppings would aggravate this trouble.

2. The means described would not seem to assure positive results without a wastage of both rock dust and labor. The dust may not deposit just as you would like it to. The results of the sampling might be misleading.

3. The expense of dusting these returns would be greater than the use of concentrated barriers at junction points of the return air current. Furthermore, the relatively higher moisture content in return air would have a tendency to dampen a thin veneer of rock dust, which would not be true in the same degree of the concentrated barrier.

5. With no traveling and no electricity in the main return ventilating current, the danger of an explosion originating there would be at a minimum. I refer, of course, to the long stretches of return airway where the adjoining coal has been exhausted, or where the active workings have moved on. The concentrated barrier should prevent any explosion being propagated through the return.

MR. THOMAS G. FEAR: I would think a combination of the two would work out very well—that is, rock dust your main haulageways and intakes completely and then between junction points and long returns put rock-dust barriers at either end. There is no travel in that return with lights or wires or anything to cause explosions, so your rock-dust barrier at either end would prevent the flame from

*Superintendent Vesta Coal Co., Vestaburg, Pa.

passing from one section to another. That will have to be taken up because it will be pretty difficult to dust every square foot of a coal-mine. Anybody who attempts to do that will find quite a job ahead of him.

MR. GRAHAM BRIGHT:* I understand that in some of the mines in the redusted Southern Illinois district they have so much dust that the haulage-ways are ankle deep in places, and they just let it lie there and when anybody walks through it kicks up a lot of dust in the air. Is it good practice to let the dust stay on the floor or should they clean it up?

MR. THOMAS G. FEAR: Is that rock dust?

MR. GRAHAM BRIGHT: A good deal of it is rock dust; but it has some coal-dust mixed with it. Isn't there an objection to having so much of it on the floor and kicking up dust all the time? Under these conditions there is always more or less dust in the air.

MR. THOMAS G. FEAR: My theory has always been that the dust on the floor is less important. It is a lot easier to put the dust in suspension if you have it on ribs and roof than on the floor. We do not put rock dust on the floor; we put it on the ribs and roof. I would not have any kind of dust ankle deep. I think that is why some of the mines are so dangerous; they do not clean up their headings; they let the coal pile up to the top of the rails, and they have a pulverizer every time a trip comes by, and it makes more dust. That is absolutely a wrong way of mining coal. It is not safe.

*Consulting Engineer, Howard N. Eavenson & Associates, Pittsburgh.

HIGHER THERMAL RESULTS IN THE BOILER ROOM, AND THE RELATION BETWEEN EFFICIENCY AND ECONOMIC VALUES*

By Joseph G. Workert†

Introduction. It is time to initiate a serious discussion concerning the relations which the elements of different methods of fuel burning bear to each other. It is necessary not only to examine the present situation somewhat in detail, but also to look into the history of installations out of which this situation was evolved, in order to realize what is happening and in order to discuss the steps that have been and are being taken to obtain the results now being talked about and published.

It may as well be said at the outset that I have not come, and do not expect to come in this paper, to any unalterable conclusion as to the particular policies which you ought to adopt. I expect only to open the subject, point out some of the facts, try to present the deductions that naturally bear upon this subject, and ask that they may have your unprejudiced consideration as engineers.

First of all I should like to point out that there are installed in the United States to-day 12,000,000 horse-power of stokers, and that stokers are being installed at the rate of 750,000 horse-power a year. It is not generally realized how comparatively few are the installations of other methods of fuel burning. (See Fig. 1.) Oil burning constitutes only a small percentage of the total rated horse-power installed, and pulverized coal not much over one per cent.

The significance of the above figures is that we have millions of horse-power of stokers already installed in the United States and that they are being installed at a rapid rate, because the mechanical stoker is the universal method of burning coal in our power-plants. The installation of a stoker is no longer an unusual or spectacular thing and consequently no great ado is made about it and we do not hear of every installation. Furthermore, we should not forget that, because of this 12,000,000 horse-power we have installed, we know more about combustion than we knew before; and now we are going about the job of building up the efficiency of this vast boiler plant. Stoker

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plants of all kinds are burning in the neighborhood of 200,000,000 tons of coal a year, and while we all seem to be much concerned about one or two per cent. in the thermal efficiency of future installations, the economic value of this one or two per cent. is as nothing compared with the huge savings we can effect in the burning of this gigantic volume of coal.

Already, engineers are giving thought to building up the thermal efficiency of older plants. Installations of more modern stokers,

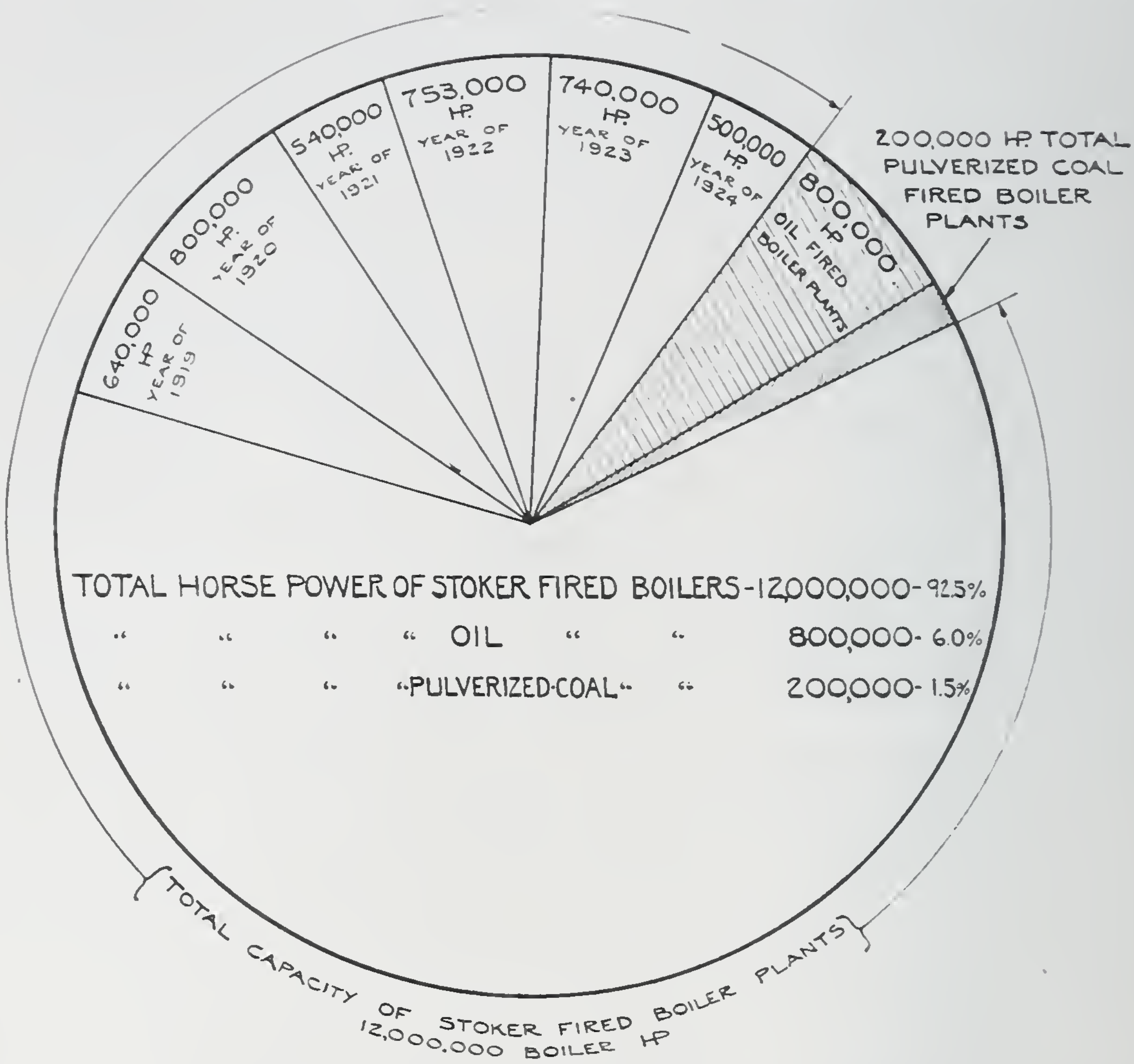

Fig. 1. Chart Showing Rated Boiler Horse-Power of Stokers, Oil-Burning and Pulverized-Coal Installations in the United States.

revamping of old stokers, and a wider and more effective use of combustion controls and heat-recovery devices are going on to-day. All of these factors together are going to effect a saving of from 8 to 10 per cent., and in some cases as high as 25 per cent., of the coal consumed in this rapidly growing 12,000,000 horse-power plant. It will be shown later that the greatest promise of attaining this end lies in the future development of the mechanical stoker and the utilization of its

possibilities to the fullest extent by the development of easily installed heat-recovery devices.

Development of Pulverized Coal in the Cement Industry. Much has been published tending to make it appear that pulverized coal is a recent innovation offering great possibilities for future development, and even in a discussion* at the December, 1924, meeting of the American Society of Mechanical Engineers in New York, attention was called to the newness of this method of burning coal and the comparative maturity of the stoker. An investigation of this situation, however, shows just the opposite to be so. Patents on pulverized-coal-burning apparatus were taken out in England in 1831, while the mechanical stoker was introduced in this country in 1879; that is, 48 years later. This throws a new light on the relative growth and development of these two systems of combustion in the past.

Regarding the future development of pulverized coal, the cement industry furnishes a good example of what may be expected. This system has been used in the cement industry since 1890 and has reached as high a state of development as it has attained anywhere. After 34 years of experience we are provided with some interesting figures on pulverized-fuel costs of which the following are typical:

Coal pulverized	67,581 tons
Costs	
Power, per ton	19.8 cents
Operating labor (including unloading coal from cars, drying and pulverizing), per ton	49.7 cents
Repairs, per ton	12.5 cents
Total cost per ton	82.0 cents

Nothing new has been created in the pulverizing of coal that gives us any reason to believe costs should be different in using this system in power-plants. The pulverizing mills have not been improved to any extent; the transport systems are the same as have been used always; in fact, not a single element of a pulverizing unit has been introduced that has effected any improvement in the results obtainable from this system.

Among cement engineers, pulverized-coal furnaces have the reputation of being "fuel hogs." One well known engineer in addressing

*Abstract in Mechanical Engineering, v. 47, p. 19-23.

the cement industry* sums up this situation in these not uncertain terms:

> "Undoubtedly eventually we shall all have to come to the greater economy utilizing low grade fuels, such as we find so largely through the middle west, in some process of distillation, utilization of the gases and the coke—burned intimately together with the raw material; and not as we do today, blowing the powdered coal through our furnaces and carrying a large percentage of it through the stacks."

My thought in mentioning the above situation is that it seems that all of us are getting our combustion problem mixed with a lot of other elements that go to make up a complete steam-generating unit. *We must begin to discriminate between combustion processes and heat-recovery elements.* We must consider those things that are connected directly with a combustion system, and not get the different elements of the steam-generating cycle so completely mixed up that no one knows just how to go about the solution of any particular problem.

The Definite Development of the Mechanical Stoker. Now let us see what has been the situation with regard to development of the mechanical stoker in the much briefer period of its existence.

The following figures, showing the rate at which stokers have been installed during the years 1919 to 1924, based on reports of the United States Department of Commerce, are significant. The number of stokers installed in 1919 has been taken as the basis.

	Number of stokers per cent.	Total horse-power of stokers per cent.
1919	100	100
1920	78	125
1921	31	52
1922	56	115
1923	62	115

The interesting thing in connection with these figures is that while the number of stokers has decreased, the horse-power has increased. This is due to the very logical and definite development in the mechanical stoker—a development so gradual that those not intimately connected with stoker manufacturing do not realize how extensive it has been.

*Engineers and Engineering, v. 41, p. 294.

Consider the growth of the multiple-retort underfeed stoker which came into general use only about fifteen years ago. Take, for example, the modern stokers of the underfeed type being installed at the new Kearny station of the Public Service Production Company of New Jersey, representing the highest state of development of modern stokers, and compare these very efficient fuel-burning machines with the stokers of only a few years ago.

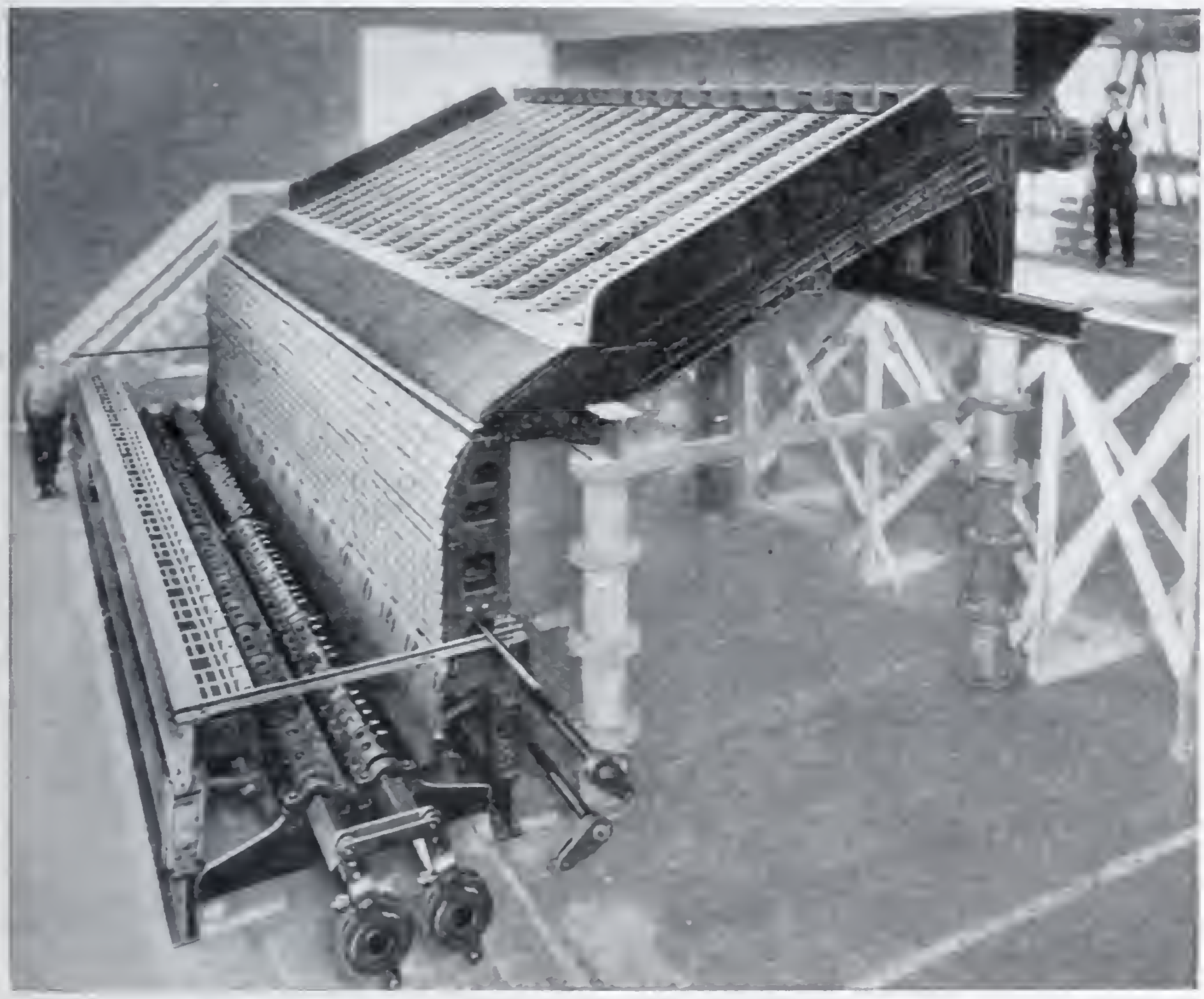

Fig. 2. Modern Stoker for Kearny Station, Public Service Production Company, Kearny, N. J.

These Kearny stokers (Fig. 2) are 24 feet 10 inches in depth, overall; 27 feet 9 inches in width, and 16 feet 3 inches in height. Fig. 3 shows this stoker and a stoker of a few years ago. It will be noted that the rotary ash discharge pit of the Kearny stoker is almost equal in depth to the length of the old stoker.

In thinking of recent stoker development, the value of this change is not generally realized, and many engineers think that the only development in stoker construction has been in the length. In the modern stoker there is a fundamental principle of design which has

completely changed the velocity of both fuel and air. This has resulted in a very decided change in the scrubbing action between these two elements.

Work is now in progress looking toward the further zoning of a fuel bed, and future developments will probably be more and more confined to portions of a fuel bed rather than the fuel bed as a whole.

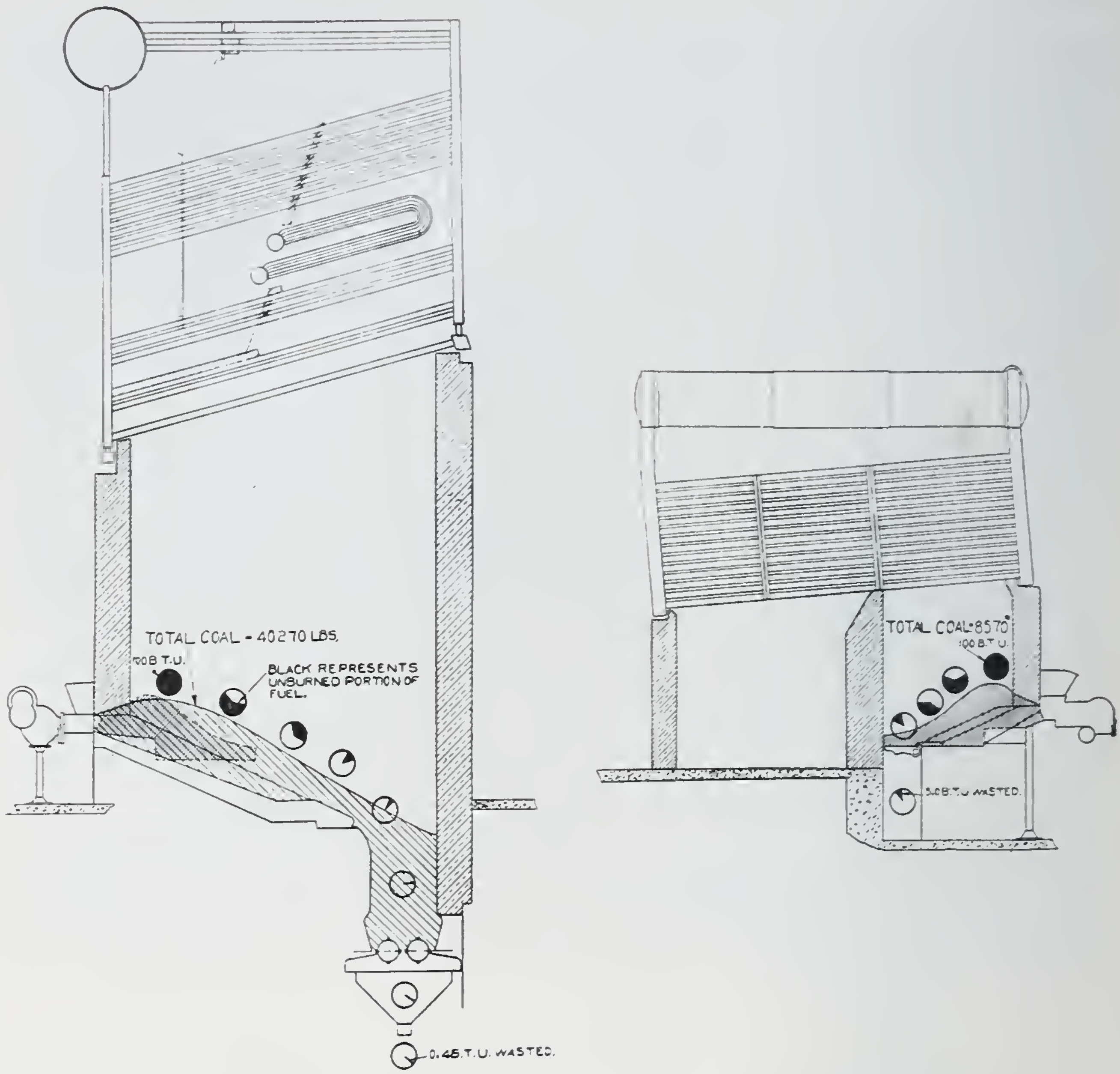

Fig. 3. Comparison of Old and Modern Underfeed Stokers Showing Development in Size.

For example, the rotary ash discharge has a vertical depth almost as great as the length of our older stokers, making it possible to design a stoker installation so that one of the largest losses in stoker operation has been reduced; namely, the combustible in the ash. The point is that a combustion system must offer quite as much opportunity to the man who wants capacity as the one who wants efficiency. The stoker

of to-day does just that. The older stoker, on high capacity runs, necessarily had to burn coal rapidly and get rid of the ash quickly because a single particle of coal had very little time to spend in the furnace. To make this clearer, a circle representing a block of coal having a heat value of 100 B.t.u. is shown entering each stoker. Successive circles indicate the movement of the block of coal through the furnace and the solid black area in each circle represents, to scale, the amount of combustible remaining at various points in its travel. In the long stoker it is almost entirely burned out before discharge. With the small stoker, about 4.2 per cent. of the heat value of the coal is found in the refuse, while with the long modern stoker this is reduced to 0.4 of one per cent. This is the unprecedented low mark recently obtained on a 28-hour run at Hell Gate station of the United Electric Light & Power Company. But the chief advantage of the long stoker over the shorter unit is its ability to burn more coal per foot of furnace width and to burn it at a higher efficiency. To this ability, principally, are credited the remarkably high capacities being obtained from modern boilers and the substantial increase in output that has been obtained, in many instances, from old boiler installations. At the Hell Gate station, for example, in an 11-hour test for capacity on the stoker and furnace combination previously mentioned an average of 461 per cent. of boiler rating was maintained and a maximum of 603 per cent. was reached.

The higher fuel-burning capacity per foot of furnace width also has made possible the building of high and narrow boilers with many times more heat-absorbing surface per square foot of floor space covered than was previously considered practical. The single long stoker also has a number of important advantages over the shorter double-set arrangement which it is rapidly rendering obsolete. It is naturally easier to operate one stoker than two, less power is required and there is much lower maintenance. Also, the single stoker gives a continuous fuel bed under practically the entire length of the tubes, eliminating the area of low combustion in the center occasioned by the ash-discharge mechanism necessarily located in this position.

In the original installation at the Hell Gate station, two 14-retort stokers, each 17 tuyeres deep, with a double-roll, rotary ash discharge between them, were used under each boiler, having a depth between end walls of 19 feet 1 inch.

In the new installation, a single 33-tuyere stoker with rotary ash discharge takes the place of the two stokers and, while it is much longer than its 17-tuyere predecessor, it reduces the furnace depth between end walls to 15 feet 6 inches.

A summary of the principal advantages of the modern stoker of latest design follows:

1. Enables more coal to be burned per foot of furnace width.
2. Affords greater length of high-temperature zone.
3. Permits use of high and narrow boilers.
4. Results in more uniform thickness of fuel bed.
5. Gives higher efficiencies at high ratings.
6. Allows greater stoker area to be installed under old boilers.
7. Provides better fuel-bed conditions for high-ash coals.
8. Burns out the fuel more completely.
9. Lowers cost of installation.
10. Does away with double-ended stoker applications, therefore reducing power consumption and maintenance and simplifying operation.
11. Allows entire lower row of boiler tubes to receive radiant heat, reducing furnace temperature.
12. Reduces cost of stoker installation per unit of capacity.

Improvement in Performance of the Mechanical Stoker. Recent stoker development can be divided into four periods, and curves indicating the performance of stokers from each period are shown in Fig. 4.

The first period takes in the years from about 1910 to 1914. During this time most stokers were operated with natural draft, except the multiple-retort underfeed stoker, which used forced draft. The original multiple-retort underfeed stoker was made in a few sizes only. It was short, had no extension grate, and was crudely built. As most of the boiler settings were wide at that time, when more capacity was wanted, it was obtained by building up the stoker in width through the addition of more retorts.

The next period extends from 1914 to 1920. During this period the longer stoker with better fuel-bed control began to make its appearance with a decided increase in efficiency and capacity.

Then, about this time, boiler design began to undergo a change to take advantage of the much higher fuel-burning capacity per foot

of furnace width of the modern stoker. During this third period, high and narrow boilers and long stokers became the rule, with the result that with this combination the Hell Gate station of the United Electric Light & Power Company, in New York, has obtained efficiencies

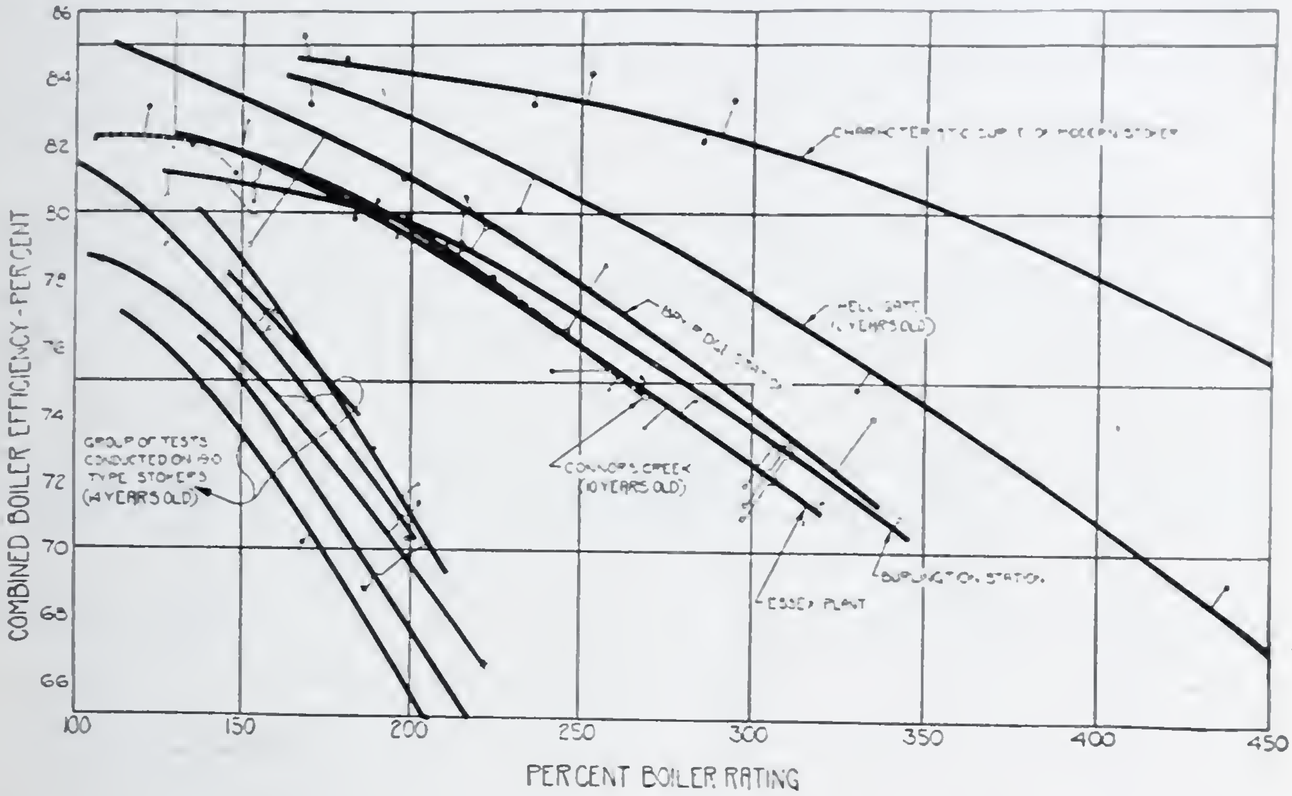

Fig. 4. Performance Curves, Old and Modern Stokers, Showing Development at High Fuel-Burning Rates.

and capacities which never have been equalled by any other system of combustion.

In the fourth period a number of improvements have been brought out in the design of new stokers, the most important of these being the velocity of fuel and air in the different zones of the fuel bed. All of the parts have been proportioned with respect to the progress of the fuel from the point of entry until its discharge as ash. Whereas a few years ago dump grates were the usual practice, the rotary ash discharge is now used. At first the ash well was made shallow; now it is made of considerable depth. It was a new thing to vary the design of a stoker to control the travel of the coal vertically, because formerly every one thought of fuel moving horizontally. The modern long stoker effectively controls the feed of fuel both horizontally and vertically.

Heat Losses and Heat Recovery. Before we can hope to compare fuel-burning equipments for power-plants, we must have a clear

idea of the elements involved, whether the coal be of large size or in pulverized form.

Many have the idea that in the burning of coal in pulverized form something happens in the chemical combination of elements that doesn't happen when the coal is burned in lump form. The only difference is that in the one case the particles of a lump of coal are burned separately, while in the other case they are burned collectively.

In order to show clearly just what heat losses occur in our different methods of burning coal, a chart has been prepared (Fig. 5) showing graphically the heat losses from three different tests in connection with stoker practice, and two taken from pulverized-coal practice.

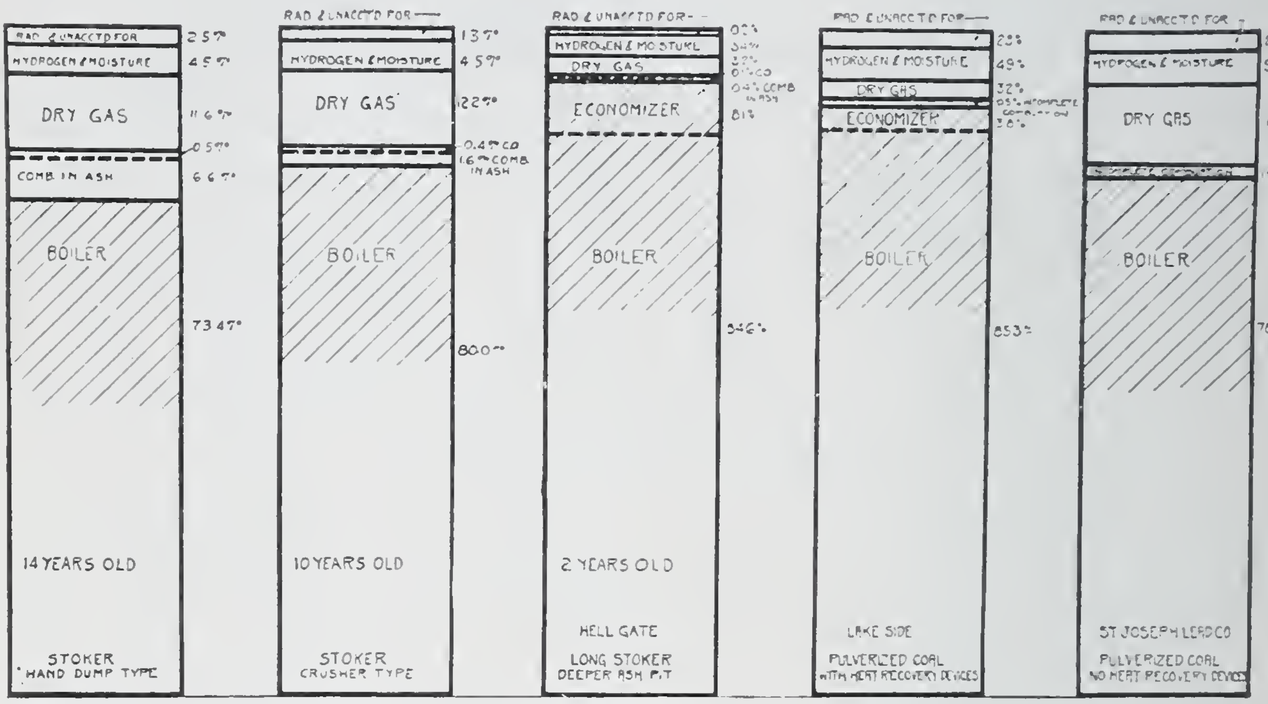

Fig. 5. Heat Balances, Stoker-Fired and Pulverized-Coal-Fired Plants.

The first rectangle shows the different heat losses of a typical test on the previously mentioned stoker that was used 14 years ago. The second shows the heat losses of tests conducted on stokers that were in use about ten years ago. The next shows the losses with equipment such as tested at the Hell Gate station, New York. The next shows the losses as reported at the Lakeside station of the Milwaukee Electric Railway & Light Company, and the last shows the losses as reported in Technical Paper 316 of the United States Bureau of Mines, covering tests conducted at the plant of the St. Joseph Lead Company, Rivermines, Mo.; the last two being pulverized-fuel plants. From all of these it is seen that an increase in efficiency can be made

by decreasing losses due to radiation and combustible in the ash, and by reducing the temperature of exit gases.

Experience has shown that reduction of excess air is limited by the endurance of refractories. Commenting on this feature in connection with burning pulverized coal at the St. Joseph Lead Company installation, the above Technical Paper of the United States Bureau of Mines says, on page 21:

"When an attempt is made to operate the furnaces of the Rivermines plant with low excess air and high CO_2 in the flue gases, the temperature in the furnace becomes so high that the ash at the bottom of the furnace melts and cannot be removed while the furnace is in operation. The high temperature also causes excessive erosion of the furnace lining, because the melting point of the ash in the Illinois coal is so low that the ash melts completely at the high furnace temperatures, runs over the brick lining, and erodes the brick."

Particular notice should be taken of the losses shown by the St. Joseph Lead Company as compared with those of the Lakeside station, both of which are pulverized-coal plants. In this connection the Technical Paper mentioned above, referring to the tests at the St. Joseph plant, says:

"But the efficiencies in these tests are low as compared with the results of the tests made at the Lakeside Station, Milwaukee, which gave boiler efficiencies 7 to 8 per cent higher than the two Stirling boilers of the Rivermines plant gave. The reasons for the higher efficiency of the Lakeside plant are:

1. Special provision of water screen and air-cooled hollow walls, to prevent erosion of furnace lining and the slagging of the ash at the bottom of the furnace, which made possible the operation of the furnaces with a low excess of air.

2. The four-pass boilers of the Lakeside plant are much better heat absorbers than the three pass boilers of the Rivermines plant, consequently the gases leaving the four pass boilers have a temperature about 130° F. lower than those from the Stirling boilers.

On account of these two features, the heat losses in the dry chimney gases of the Lakeside boilers are 7 to 10 per cent, whereas for the Rivermines boilers they are 12 to 15 per cent. For the hollow furnace walls of the Lakeside station the radiation losses are about 1½ per cent less than they are for the solid furnace walls of the Rivermines plant. The difference in these two losses nearly accounts for the difference in the efficiency of the two boiler plants."

This statement is very significant, especially if we should attempt to compare methods of burning coal. Here we have two plants employing the same system of combustion. One of them is equipped with certain heat-recovery devices not incorporated in the other and has an efficiency seven to eight per cent. higher. It seems to me that this not only indicates but proves that the higher thermal results obtained at Lakeside were due to physical heat-recovery devices rather than anything that might be inherent in pulverized-coal burning, and it also shows the results that may be expected with pulverized coal when installed under conditions usually imposed on stokers.

Modern Stoker Performance Curves. It should be noted from Fig. 4 that there seems to be a very definite characteristic curve for stokers for each period of development. Even in the early years of the underfeed stoker, this characteristic performance curve seems to be a definite formula. Great as is the development so strikingly brought out by the Hell Gate curve, it is still well below the performance that reasonably may be expected from a still more effective combination of stoker with boiler and heat-absorbing elements. A curve of this performance is also shown. It is plotted from data based on a large number of performances already obtained.

A paper* presented before the American Society of Mechanical Engineers in December, 1924, gives a number of pulverized-coal tests. In an endeavor to find the characteristic performance boiler-rating curve, all of these tests were plotted as shown in Fig. 6, giving the relation between efficiency and boiler rating. There seems to be a very wide variation in these results, and the range of operation seems very limited.

This paper, however, did not give any of the results obtained in the tests at the plant of the St. Joseph Lead Company as published by the United States Bureau of Mines, and these tests were plotted because they show the results obtained with pulverized coal with ordinary boiler construction, such as solid brick walls, and with no water screens, no hollow wall construction, no economizer, no heat-recovery advantages, no combustion control, etc. A curve of the Lake Shore plant of the Cleveland Illuminating Company has been added also.

*Abstract in Mechanical Engineering, v. 47, p. 19-23.

These same results were plotted to show the relation between efficiency and the coal fired per cubic foot of combustion space per hour. The result is as shown in Fig. 7. Still there is no characteristic curve apparent.

Comparison of Tests of Stoker and Pulverized-Coal Equipment. During the last two years a number of companies have each equipped one of the boilers in their respective plants with one pulverized-coal equipment to find out what results could be obtained.

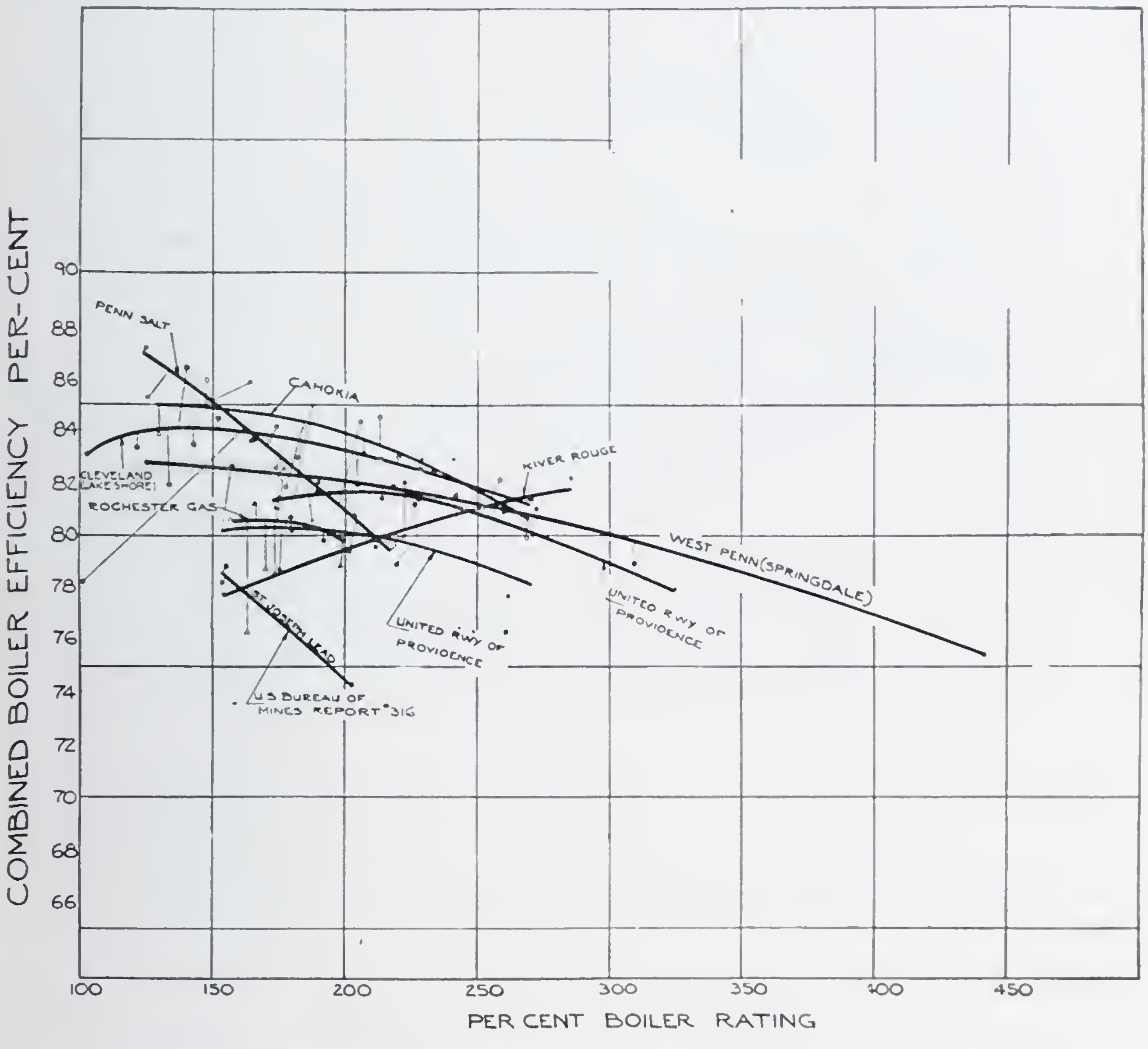

Fig. 6. Relation Between Efficiency and Boiler Rating. Pulverized-Coal Tests.

In each case the installation of this one unit has had the best engineering co-operation available. In fact, I was told not long ago that each of such installations cost $10,000 for engineering and drafting alone. After this unit has been put in operation it is carefully tested, modified, and retested, until it is felt that the maximum possible efficiency has been obtained from that single unit. Results so

obtained are then used as the basis of comparison with results obtained from an installation of stokers in the same plant—stokers which in most instances have been installed ten or fifteen years.

In no case do the tests on these stokers show any similar attempt to secure from them their highest possible efficiency. Naturally the results of some of these comparisons, many of which have been published, appear to be ridiculous. Such a comparison is well represented in Fig. 8, where a pulverized-fuel equipment has been installed under

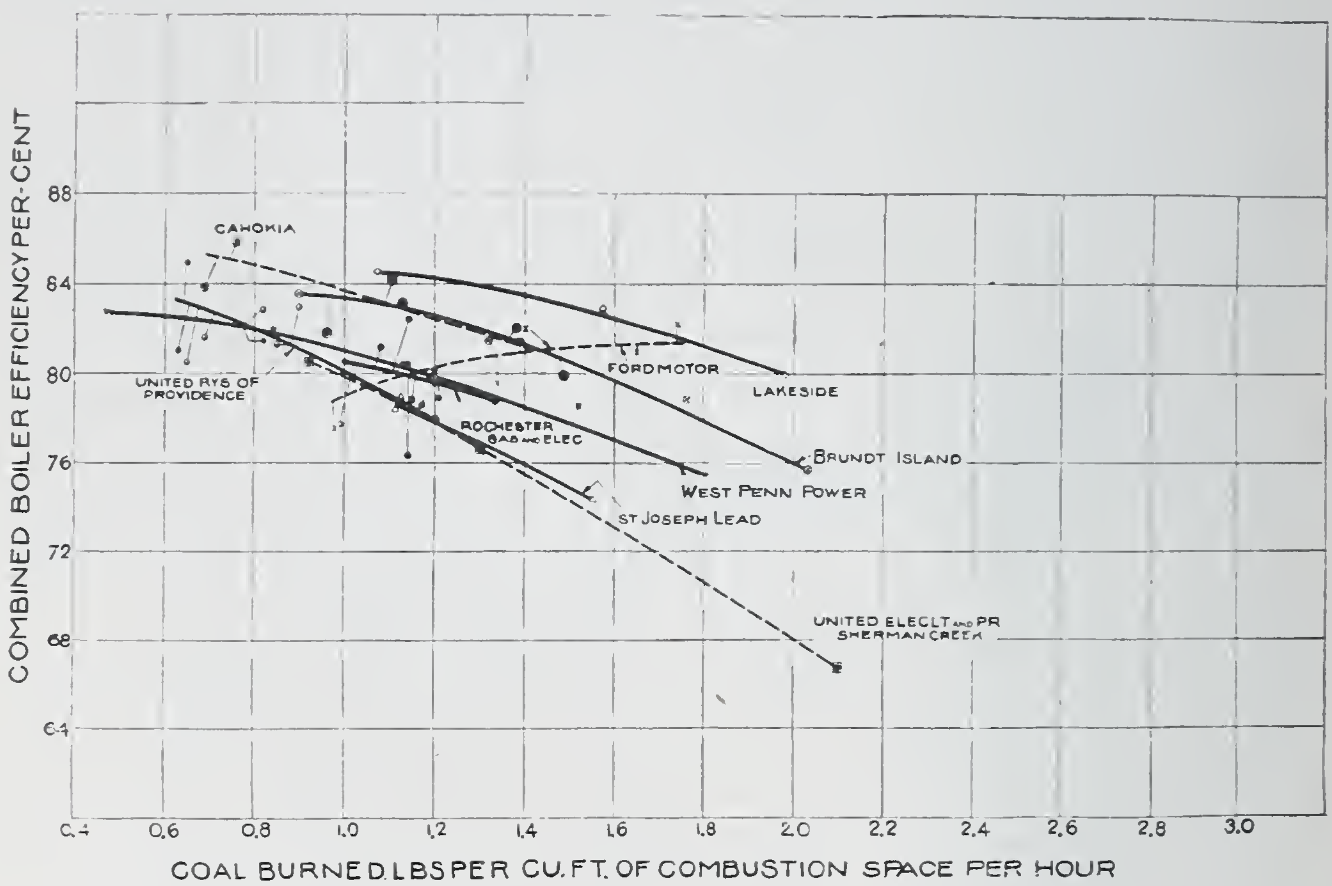

Fig. 7. Relation Between Efficiency and Combustion Rates. Pulverized-Coal Tests.

a modern boiler in a modern furnace setting. The figure illustrates a comparison which was made in that plant with an old stoker of very short length; in fact, the poorest one in the plant.

On this same figure is shown the performance of a modern stoker. The contrast between the old stoker and the new is almost beyond the imagination of an engineer who has in mind only the various gradual developments that have taken place. Notwithstanding this amazing difference, the short stoker in the instance mentioned above formed the basis of comparison with the pulverized-coal unit.

The old stoker had solid walls. There was no water cooling, nor any of the elements that generally are put into a pulverized-coal unit. Even under the same conditions of installation as prevailed with the old stoker unit, a longer stoker would have obtained results as shown in Fig. 8 by the curve representing large stoker application. Give this modern stoker the advantage of a modern setting with water-cooled walls and other heat-recovery devices and the results that reasonably could be expected are indicated by the upper curve. Now please note

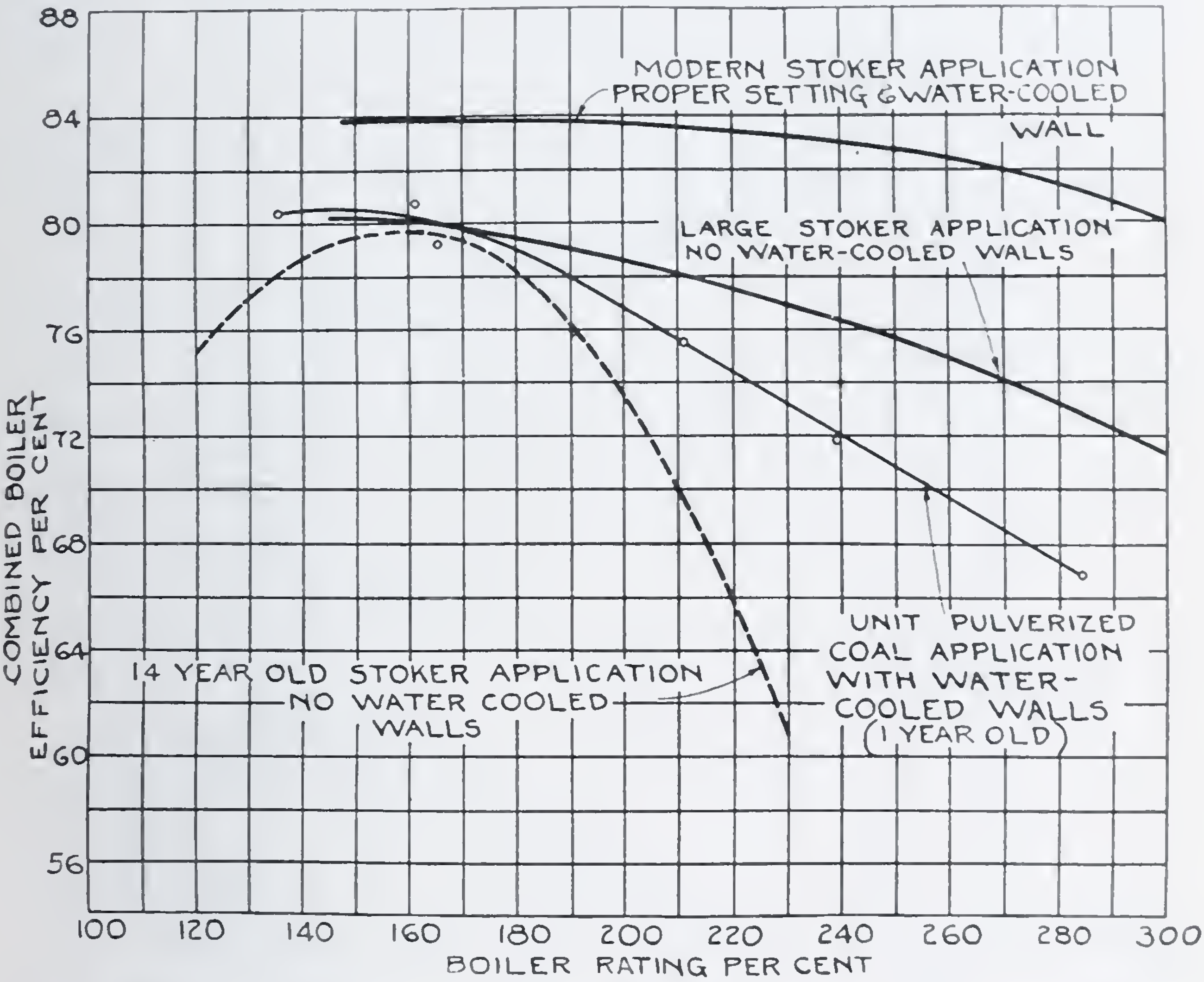

Fig. 8. Performance Curves. Old and Modern Stokers in Old and Modern Settings; Also, Pulverized-Coal Unit.

that it is the upper curve which represents the stoker installed on conditions exactly comparable with those of the pulverized-fuel-burning unit.

The first cost of a pulverized-fuel plant is markedly higher than the first cost of a stoker plant, and it probably will be found that it will be necessary constantly to add elements to an inadequate design of pulverized-fuel plant, when some of these elements are not estimated in the beginning.

Table I gives the relation of economic values in burning coal on mechanical stokers and in pulverized form. It represents a 100,000-kilowatt plant operating at 45 per cent. capacity factor and with 1.5 pounds of coal per kilowatt-hour.

TABLE I. ECONOMIC VALUES IN BURNING COAL ON MECHANICAL STOKERS AND IN PULVERIZED FORM

	Pulverized coal	Stokers
Average boiler rating (with one boiler out)	190%	250%
Gross boiler efficiency	82%	82%
Total number of boilers	13	10

Cost of three extra boilers with all equipment necessary	$1,230,000
Extra cost of pulverized-coal equipment over and above that required for stokers (for 10 boilers)	432,000

Extra maintenance required for pulverized coal at 0.12 cents per ton (0.12 × 264,000)	$ 31,700
Excess labor required for pulverized-coal plant	11,500
Cost of extra power required for pulverized coal—18 kilowatts per ton at 0.5 cents per kilowatt-hour—264,000 × 0.9	23,700
Capital charges at 12.5% on increased investment for pulverized coal—12.5% of ($1,230,000 + $432,000)	208,000
Extra annual cost when pulverized coal is used	$274,900

It will be noted that 10 stoker-fired boilers are considered as against 13 pulverized-coal-fired boilers.

An examination of the leading stoker and pulverized-coal plants shows that, for equal kilowatt outputs, this is the proportion of boiler horse-power installed. This is due principally to the much higher ratings at which stoker-fired plants can be, and are, operated. For example, it is reported that the Lake Shore plant at Cleveland is operating around 180 per cent. of rating, while the monthly average at the Hell Gate plant is 237 per cent.

How then, is it possible to justify the installation of pulverized coal? It can be justified only if positive assurance can be had that these three conditions will result:

1. That the net efficiency (efficiency of fuel burning, minus the proper deductions, such as power for grinding, drying, transporting, etc.) will be higher than the gross efficiency obtainable with stokers.

2. That the steaming capacity will be higher, both with respect to average output and maximum output.

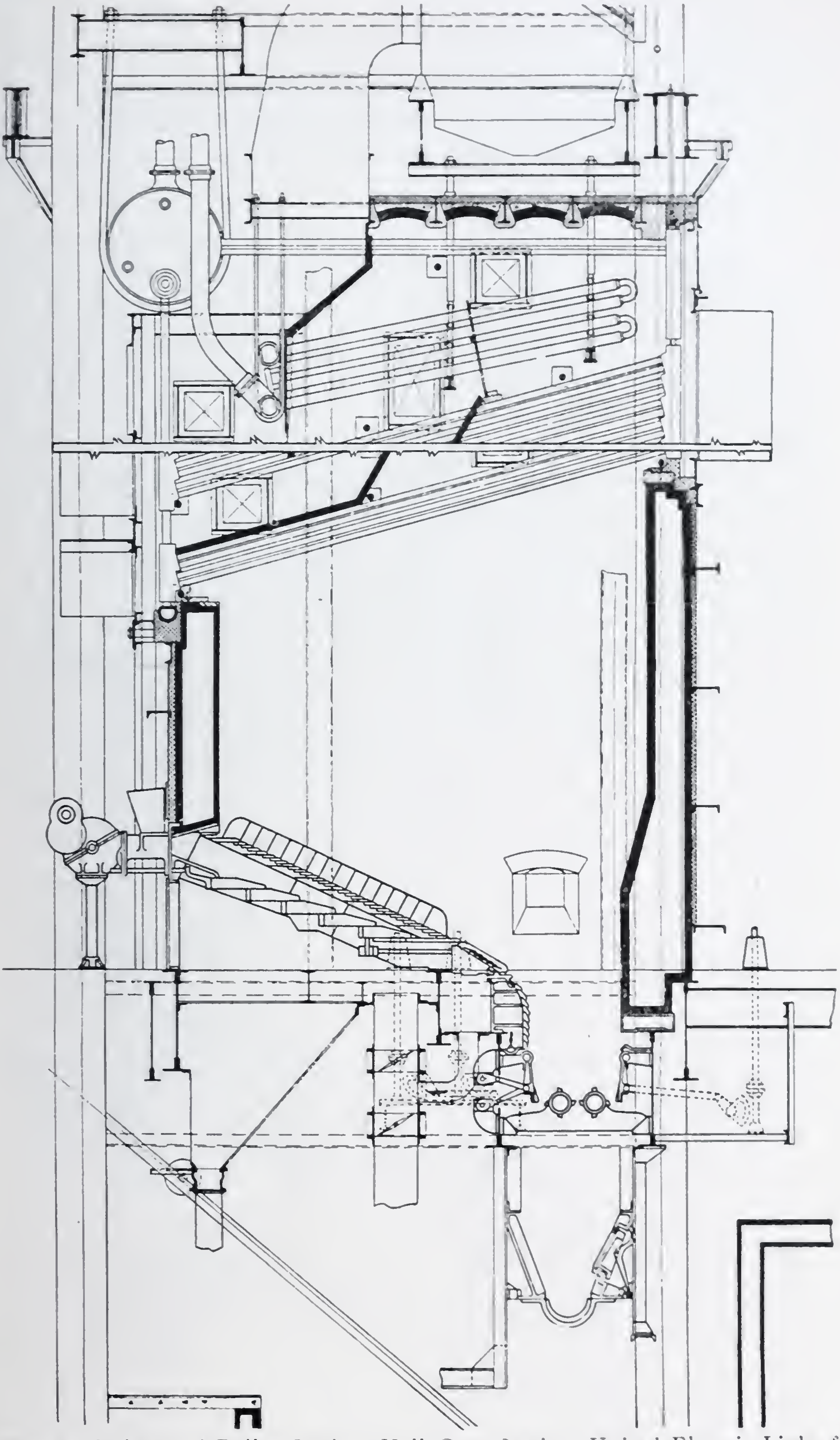

Fig. 9. Stoker and Boiler Setting, Hell Gate Station, United Electric Light & Power Company, New York.

3. That these results will be enough higher to make up for the tremendous difference in initial and operating costs.

In the light of results obtained with stokers at the Hell Gate plant, it is very difficult to conceive of any case where pulverized coal can do these things.

A Change in Engineering Equipment. If what I have already said is clear, it will be apparent that the present fuel-burning situation involves much more than just a few simple fuel-burning devices. It involves a complete and complicated system of fuel handling and processing, fuel burning, air handling and processing, ash handling and processing, heat-conversion devices for water, air, and combustible gases, and the proper proportioning of all of these elements with respect to one another. It is a system which strikes at the very root of fuel-burning economies. Even so simple a matter as establishing heights of boiler settings calculated to give generally good economic fuel-burning results formerly meant several years' struggle to stoker manufacturers. To-day these conditions have changed. There is no single element, from coal pile to steam, that is not indicating radical changes, with even more radical changes in prospect. In the past, mechanical stokers have been bound literally by hundreds of restrictions, physical and otherwise. With many of these restrictions removed or eliminated, free opportunity is at hand to develop the full possibilities of the mechanical stoker. Only a few years ago the design for air-cooled furnace walls was rejected as being too costly and too complicated. To-day the engineer who is interested in securing the best thermal results in a boiler plant must contemplate the complete system which makes those thermal results possible. It is not possible to set arbitrary limitations here and there and expect to secure final results that will be within striking distance of the possible maximum. For example, in the West there has for many years been a disposition to sacrifice efficiency of fuel burning to secure efficient handling of ashes and clinker. This is perhaps an excellent case in point. This, if I may be permitted to say so, is not the way to solve the problem of burning low-grade types of fuels. Obviously, the way to solve this problem is to make the fuel-burning apparatus as efficient as possible and at the same time put the necessary brains and money into the solution of the problem of clinker and ashes.

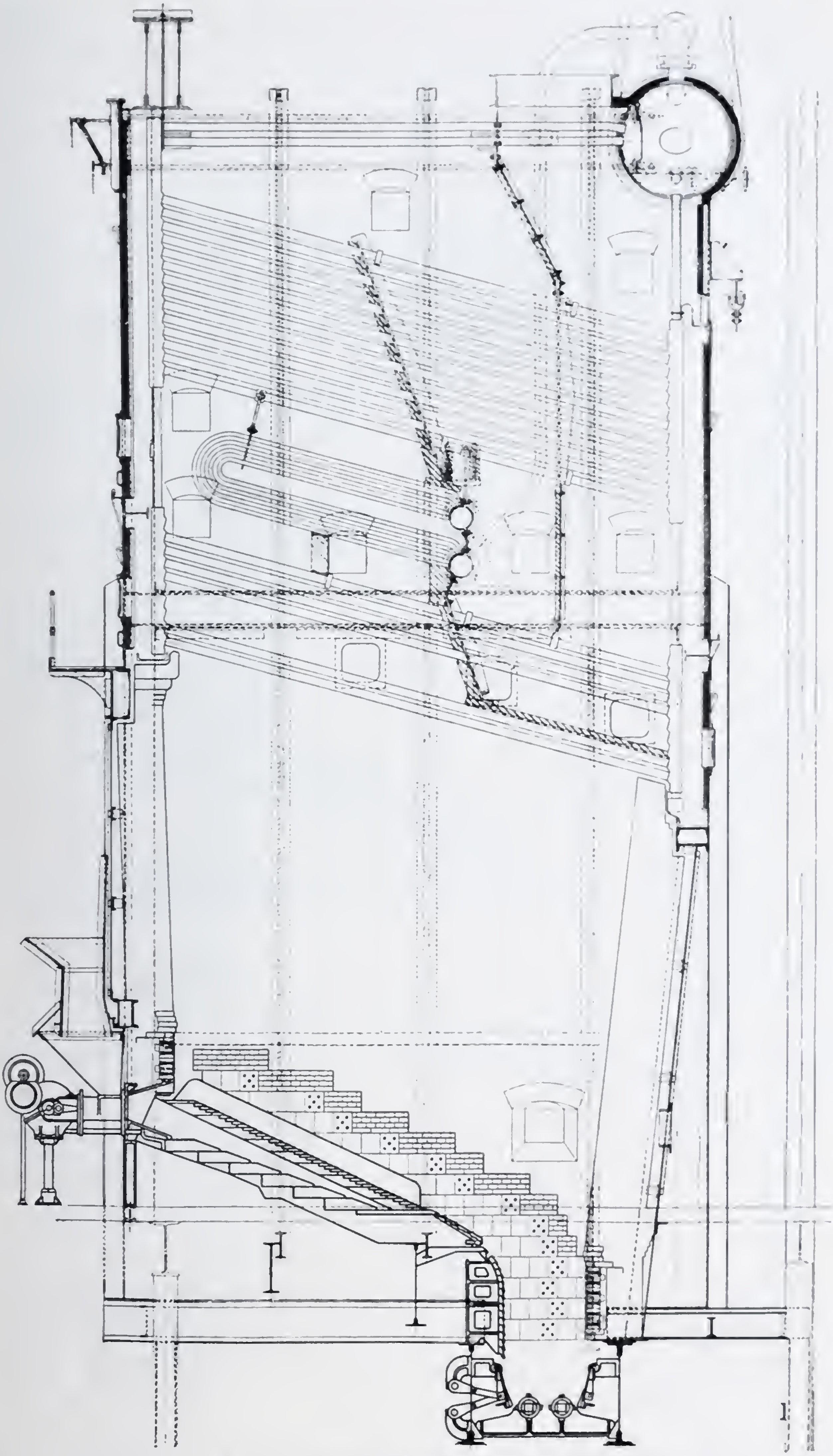

Fig. 10. Stoker and Boiler Setting, Kearny Station, Public Service Production Company, Kearny, N. J.

Summary. Briefly, to sum up what I have said, the following will be apparent:

1. I have shown you that there are 12,000,000 horse-power of stokers installed in the United States. This represents about 75 per cent. of all boilers of 300 horse-power, or over. I have also shown you that stokers are being installed at the rate of 500,000 to 750,000 horse-power per year. I have shown you also that all other plants, fired by oil and other processes, not including hand-fired plants, are not worth considering in this situation.

2. I have shown you where the engineer is confronted by a real and existing problem of increasing the efficiency of this vast power-plant from 10 to 25 per cent.

3. I have shown you where the improvements employed in new stoker-fired plants create a similar opportunity for increasing the efficiency and the steam output in existing power-plants.

4. I have shown you where almost all other fuel-burning equipments have thermal advantages of one kind or another not present in the average stoker installation; some of these consisting of the following:

   a. Apparatus for drying the moisture out of the coal.

   b. Hot-air recoveries from the furnace walls which reduce the radiation and benefit combustion by heating the air.

   c. In every case, practically double the furnace volume for burning the gases.

5. I have shown you where the characteristic efficiency curve of the stoker plant will be actually higher and flatter than the characteristic efficiency of the pulverized-fuel plant of the same comparable basis of installation.

6. I have shown you where the steaming capacity obtainable with modern stokers is higher than with any other fuel-burning method, both with respect to average output and maximum output.

7. I have shown you where, with elimination of many of the restrictions that were put on stokers in the past, a free opportunity is at hand to develop to the fullest extent the grèat possibilities of the mechanical stoker—inherently the simplest and most economic system of extracting heat from coal.

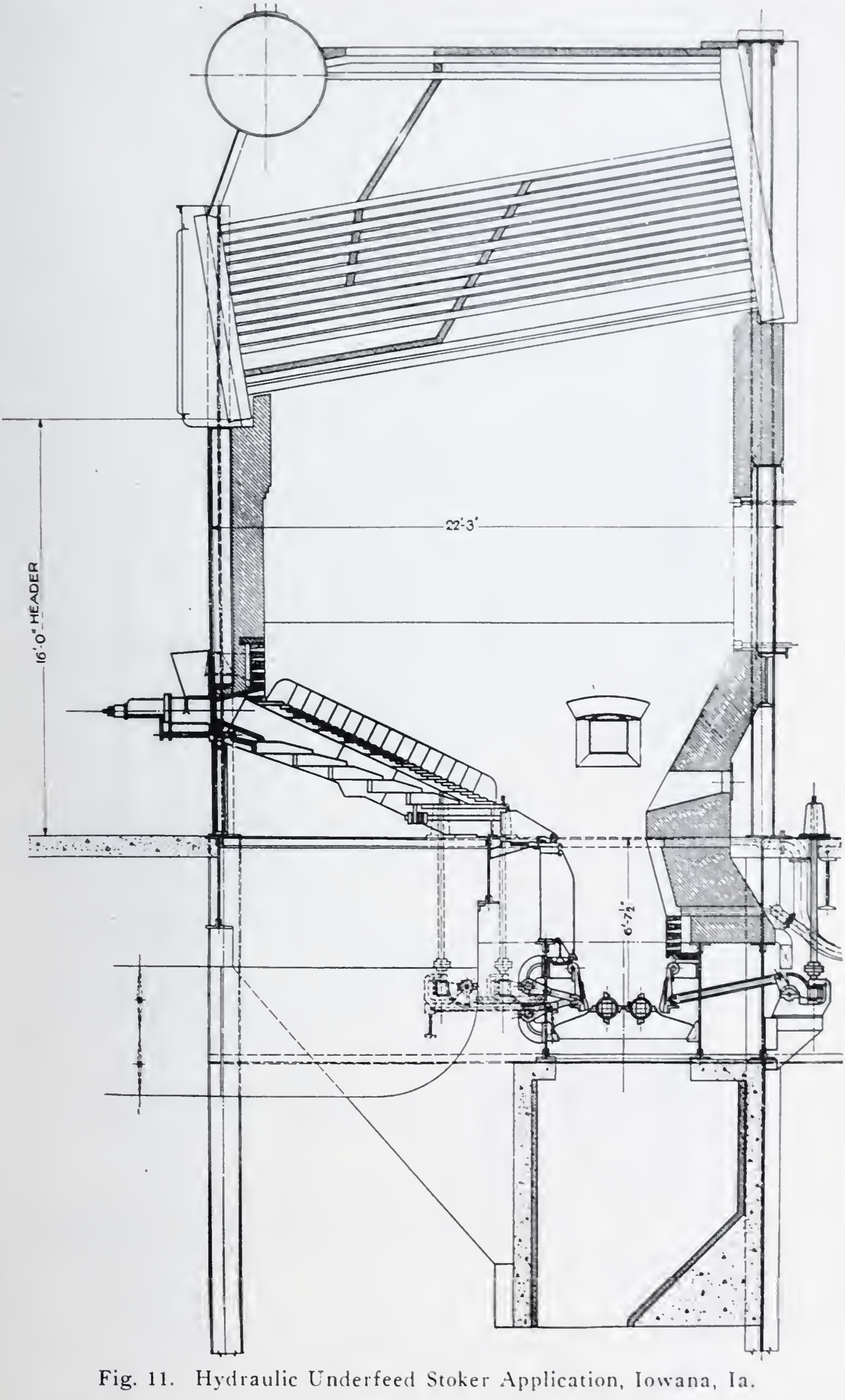

Fig. 11. Hydraulic Underfeed Stoker Application, Iowana, Ia.

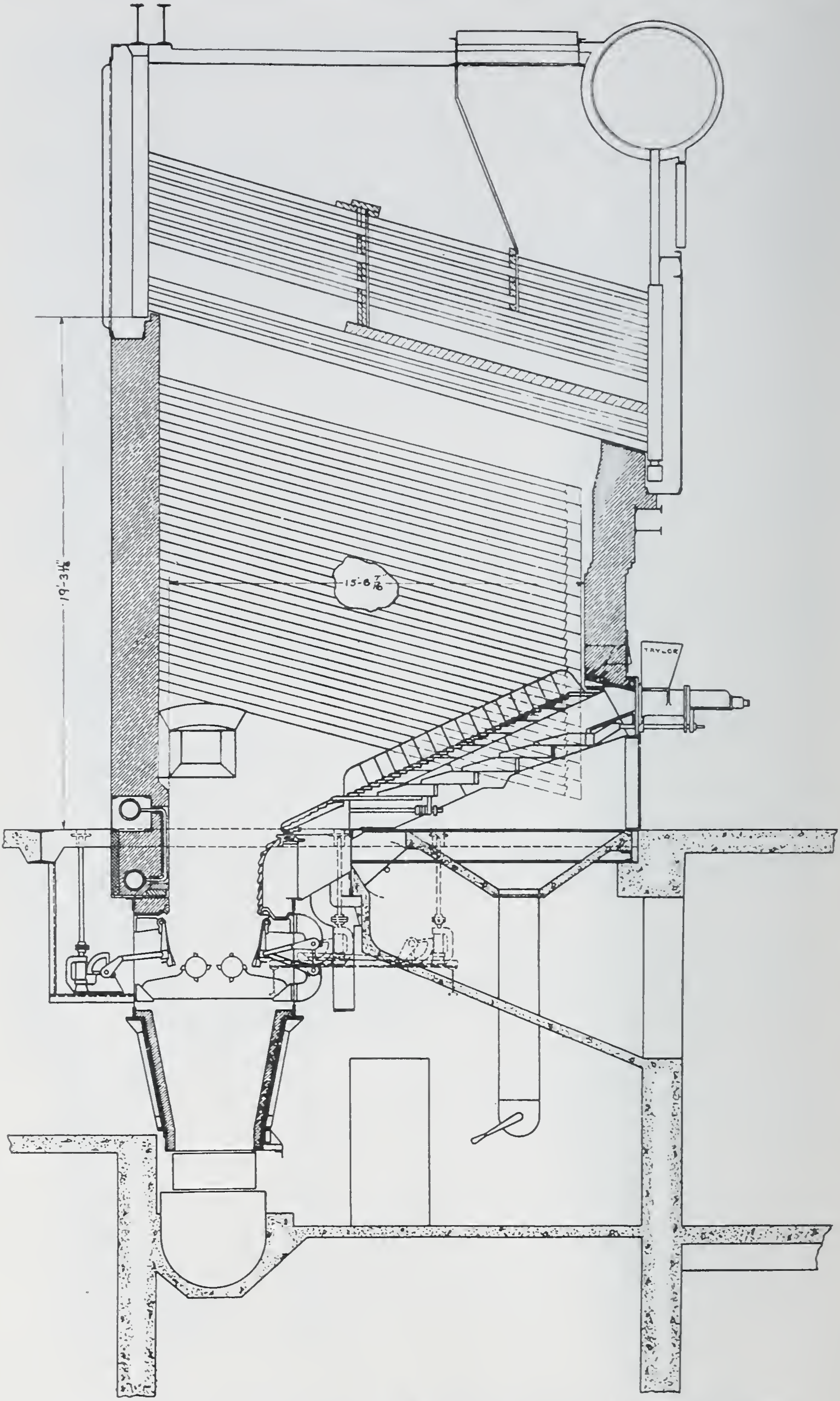

Fig. 12. Hydraulic Underfeed Stoker Application at Consumers Power Company, Zilwaukee, Mich.

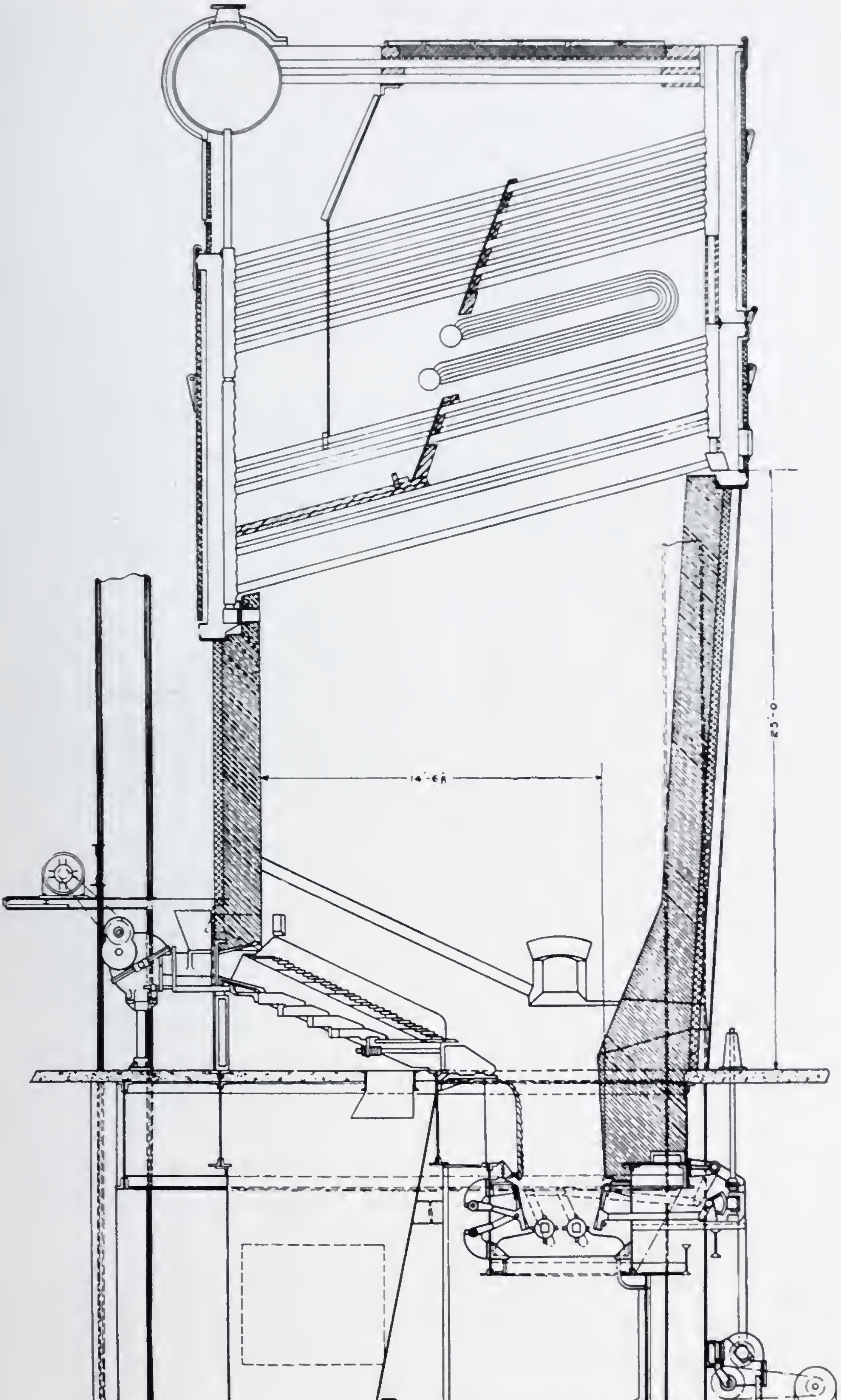

Fig. 13. Stoker and Boiler Setting, Weymouth Station, Edison Electric Illuminating Company, Boston.

DISCUSSION

Mr. L. C. Frohrieb:* We have certainly enjoyed Mr. Worker's very interesting and instructive paper. In his preliminary remarks he stated that the City of Pittsburgh was doing away with its smoke inspectors. I wonder whether this was not a rather delicate compliment to the stoker manufacturers by our city officials; they realizing that these manufacturers would soon have our city smokeless by installing stokers in the various plants.

As I was not so fortunate as to receive an advance copy, I shall not try to discuss the paper without giving it more careful analysis, but I should like to ask whether the curve shown is a theoretical one, or have these efficiencies already been obtained throughout the entire range shown?

Mr. Joseph G. Worker: Yes, I would say that it has been obtained. These guarantee curves are quite commonly used in stoker practice. It has been proved that they are conservative and power-plant operators have found it safe to rely on the figures and data presented in the curves as a measure of the performance to be expected from their boilers and stokers.

Mr. John A. Hunter:† I did not have the opportunity of seeing an advance copy of Mr. Worker's paper, so that I have not come prepared to discuss it. However, I have been very glad to hear his very interesting presentation of the recent developments in stokers, and also the excellent efficiencies which are being obtained from the Hell Gate station, where the most improved type of modern stokers is being used. This paper is of particular interest to me, because at the annual meeting of the American Society of Mechanical Engineers the advocates of powdered coal apparently had everything their way, and would almost persuade one that the stoker was relegated to the scrap heap. I have not become so enthusiastic over the use of powdered coal as to agree with this theory, for I believe (although the use of powdered coal is going to be greatly extended) that for some time, particularly for industrial work and until a great many things in

*President, Federal Engineering Co., Pittsburgh.
†Steam and Sanitary Engineer, American Sheet & Tin Plate Co., Pittsburgh.

the preparation and firing of powdered coal have been worked out, stokers will still be used.

I would like to ask Mr. Worker whether he believes that with the coal used in this district—with a relatively large amount of ash of low fusion point—efficiencies can be obtained as high as those at Hell Gate station, where I understand the coal used is low in ash and with a low fusion point.

Mr. Joseph G. Worker: In answer to Mr. Hunter's question, I wish to say that the coals in the Pittsburgh district can be burned with the same degree of efficiency as the coals burned at the Hell Gate station. Having regard for the necessary loss in burning any particular kind of coal, the burning of most of the Pittsburgh coals would represent substantially the same efficiencies as obtained at the Hell Gate station; or, in fact, better efficiencies with later and more modern stokers.

Mr. John A. Hunter: What I particularly had in mind was the use of clinker crushers on these coals. Some time ago I visited a large public-service power-plant in the East where Pocahontas coal was being used on stokers equipped with clinker crushers. They were working very nicely on this coal. I made some inquiry as to what would happen with the use of coal containing ash with a low fusion point, and was told that during the coal strike, a few years ago, Welsh coal had been burned, and that with this coal the clinker crusher was practically useless, as large clinkers were formed, which had to be pulled out the side doors of the furnace.

Mr. Joseph G. Worker: Too often we go about the solution of these particular problems by thinking of difficulties we have had in the past. The best way to design a modern stoker plant is to study the local situation, especially with regard to the poorest coal that will be used and then put in the necessary brains and money that will result in the apparatus that will solve the particular ash problems. Modern stokers being designed to-day for coal that tends to clinker are being surrounded entirely with air backs in the ash well. These ash wells are made especially for particular conditions.

The burning of Welsh coal to which Mr. Hunter refers occurred in New York and Boston several years ago during the marked

coal shortage. The two plants with which I am familiar are the Interborough Rapid Transit Company and the New York Edison Company, both of which burned Welsh coal at that time and all the loads were carried with Welsh coal. They did have some difficulty for a few days in securing as high a steam output as had been obtained on their regular coals.

All the underfeed stokers in these plants that burned Welsh coal were equipped with dump plates, and most of these were at that time twelve or fifteen years old.

Mr. Lewis Vincent:* Of all the curves shown, the only one that indicated increased efficiencies, with increased rating, was the River Rouge plant. I would like to know what factors account for that.

Mr. Joseph G. Worker: Probably those who conducted the tests at the River Rouge plant of the Ford Motor Company could answer this question better than I. The performance is unique, to say the least, but I believe it was intended to design these furnaces to burn blast-furnace gas as well as pulverized coal. The radiation and unaccounted-for losses are very high at low ratings. This may be the answer to many engineers who claim that a furnace designed for a particular kind of pulverized coal can be used efficiently for any kind of coal, gas, or oil. Perhaps other fuels or any old kind of coal can be burned in furnaces designed for pulverized coal, but what must be sacrificed in order to do it?

Mr. Sydney J. McAuliffe:† We have listened to an extremely interesting paper, indeed, from Mr. Worker, and interesting from very many points of view.

In 1921, I spent 11 months in this country examining power-plants, and my present trip is just ended, or will be shortly, after a tour of five months. With you here, in constant contact with the situation and actually in the field, I don't know how you may feel about it, but speaking as an onlooker from abroad, I have been absolutely astounded at the growth and radical changes that have occurred in your power-plant design during my absence of three years.

*Consulting Engineer, Pittsburgh.

†Consulting Engineer, Gilbert McAuliffe, Ltd., Melbourne, Australia.

The greatest bone of contention at the present moment between power-plant engineers seems to be the question of pulverized fuel versus stokers. The author stated to-night, rather jokingly to my mind, that he was not going to join issue with pulverized fuel. Yet, as a stoker man, he has in my opinion made the finest fight I have ever heard against pulverized fuel.

I don't know whether you may have had the opportunity which I have had while with you to study this question in the thorough way that I have been permitted to through the wonderful courtesy of American engineers. The author has taken the wonderful Hell Gate station, probably the best and most efficient stoker plant in the world, and compared it with what one might believe to be the most recent pulverized-coal plant, Lakeside. Lakeside is, in my opinion, a long way from the most representative practice of to-day and I think, in fairness to the pulverized-fuel people, Mr. Worker should have taken figures from the Seventieth Street plant in Cleveland, the Cahokia plant at St. Louis, the Binghamton plant of the Metropolitan Edison Company, or the plant of the Trumbull Steel Company. There are numerous pulverized-fuel-fired, steam plants in this country showing efficiency curves very much better than have been shown in Mr. Worker's curves. As a matter of fact, the curves he has shown are not from the new school of thought in pulverized-fuel firing as I have seen it.

He also goes on to state that cement engineers were considering eliminating the use of pulverized coal. This is rather interesting to me, for as consulting engineer for five of the ten Australian cement companies I had not heard of it. I should like to hear from him what they consider adopting in its place. I anticipate that he may reply that they propose complete gasification. In such case I would state that you would then have two sets of losses instead of one. We can not go back to oil. The flexibility of control of pulverized fuel seems to be its greatest single merit. Furthermore, figures actually obtained on American pulverized-fuel installations of present-day representative efficiency show an exceedingly small amount of unconsumed carbon in the ash-pits.

I deeply regret, in a way, that either Mr. Henry Kreisinger or Mr. H. G. Barnhurst is not here to-night to represent the pulverized-fuel man's point of view in this controversy. To me, however, it is

apparent, when one sees the large number of big power-plants and industrial companies going to pulverized coal, that this more recently developed method of burning fuel has more or less established itself.

I feel that those interested in pulverized coal, in introducing a new line of thought in combustion, have put decidedly greater technical effort and engineering knowledge and skill into their work than was ever demonstrated in boiler-room practice of the past. Previous practice was to sell cast-iron stokers at so many cents per pound. I think it was that kind of practice that has so deeply wounded the stoker interests.

One gentleman asked a question concerning the efficiency curve at the River Rouge plant. I think you will find that that plant is not fired exclusively by pulverized coal. It is only about 30 per cent. pulverized coal, the rest being fired by tar and blast-furnace gas.

I thank you, gentlemen, for having given me the opportunity to speak to you.

MR. JOSEPH G. WORKER: I listened to Mr. McAuliffe's remarks with a great deal of interest and attached very considerable importance to them because Mr. McAuliffe is a stranger in our country and has the point of view of an outsider.

Mr. McAuliffe will find that I did not compare the Lakeside pulverized-coal plant with any stoker plant. I compared the St. Joseph Lead Company's *pulverized-coal plant* with the Lakeside *pulverized-coal plant*. I set up the reported heat balances of these two kinds of plants and asked that you draw your own conclusions. I showed stoker performance as it was fourteen years ago, ten years ago, two years ago, and as it is to-day. I showed Lakeside performance *with* heat-recovery devices, compared with pulverized-coal performance at the plant of the St. Joseph Lead Company *without* heat-recovery devices.

I believe that if Mr. McAuliffe will compare the more representative pulverized-coal practice—that he mentions as being exemplified in the Seventieth Street plant in Cleveland, and the Binghamton plant—he will find that their efficiency curves, at different ratings, in some cases, do not exceed the performance of the Lakeside tests. The performances of some of these plants have not as yet been published but, since this paper was read, the Cleveland tests have

been published and their test performance curve (see Fig. 6) drops below the performance of other tests.

I might refer Mr. McAuliffe to the conference on "Economy in the Use of Fuel" held at the Engineers' Club of Philadelphia, January 15, 1924, at which meeting a number of cement engineers gave their opinions relative to the burning of pulverized coal in the cement industry. It was from the records of this meeting that I quoted the discussion relative to the use of pulverized coal in the cement industry.*

Entirely irrespective of the justice of the criticism regarding the attitude of the stoker manufacturers in the past, and entirely without regard to the accuracy of this criticism, it seems to me that this attitude, if true, should not concern at all the question of the relative merits of the stoker and pulverized-fuel firing to-day or in the future.

It seems to me that you gentlemen, as engineers, have to distinguish in your own minds the question of whether or not the possibilities of further development of either system have been exhausted. This might be said, however—it is true that the stoker as an engineering product has suffered in the past and still is suffering because of lack of imagination and technical skill of the stoker manufacturers, but it seems rather clear to me that such results as have been secured with the burning of pulverized coal are the results of the skilled technical brains concerned in its installation and operation rather than of any inherent merit in the process.

It should be obvious to all of you gentlemen that, with the expenditure of hundreds of thousands of dollars and with the concentrated attention of large technical staffs, it is possible to secure test results in these plants one, two, or three points higher than would be secured by the ordinary operating personnel of a power company or the ordinary operating personnel of a manufacturer. I must concede this, but I also must draw your attention to the fact that, both as a commercial situation and as an economic situation, it is quite impossible for any manufacturer or group of manufacturers to continue to maintain these spectacular demonstrations, which in the main do not affect one way or the other the results obtained in every-day practice.

*Engineers and Engineering, v. 41, p. 294.

Mr. W. H. Ritts:* I should like to ask Mr. Worker if, in his efficiencies shown for the Hell Gate station, he took into consideration the overload fans in the top of the boiler house? When they go over a 200 per cent. rating there is an extra set of fans that come in, and I believe a motor of 80 horse-power cuts in. I understood him to make the statement that powdered-coal installations blew the powdered coal out the stack. I would like him to state one instance where it does that. In making comparisons of costs of powdered coal, he took into account the drying of the coal and the power consumed. Does he mean the unit system or the storage system? There is a great deal of difference between the storage system and the unit system; and, in a great many instances, I believe, the powdered-coal men have made a mistake and have gone into an expensive storage system that was uncalled for, and there are places where they are firing coal with as much moisture as stokers are. I know of cases where they fire powdered coal with as much as 12 per cent. moisture.

Mr. Joseph G. Worker: In answering Mr. Ritts, I would say that the 92.7 per cent. efficiency at the Hell Gate station was at 180 per cent. of boiler rating. The efficiencies given were gross. If the power consumed by auxiliaries were considered, the efficiency would be reduced about 0.5 per cent. The power required for induced draft fans is, of course, not considered. At this particular plant there is only one induced draft fan per boiler and no overload fan such as Mr. Ritts has mentioned.

I did not make the statement that pulverized-coal installations discharge pulverized coal out the stack. What I did do was to quote the statement as recorded in the fuel economy meeting before the Engineers' Club of Philadelphia with particular reference to pulverized coal used in the cement industry.

Maybe Mr. Ritts had in mind the discharge of ash from the stacks of pulverized-coal plants. Since the question has been raised, I can tell you of a number of pulverized-coal installations where from 40 to 60 per cent. of the ash from the pulverized-coal furnaces is discharged through the stack over the surrounding country. This is common knowledge among engineers. I never use this as an argument against pulverized coal and merely mention it since the question has been raised. I made no mention of this in my paper.

*Chief Engineer, Spang, Chalfant & Co., Inc., Pittsburgh.

Mr. F. K. Howell:* I should like to ask if you could give us some figures of maintenance charges that could be expected in the best modern stoker practice, and in the best pulverized-fuel practice with about the same capacities.

Mr. Joseph G. Worker: At the meeting of the American Society of Mechanical Engineers in New York in December information was asked for as to the cost of maintenance in pulverized-coal plants. Mr. John Anderson, of Milwaukee, in discussing this, stated that his company had been operating a pulverized-coal plant for four years and during this time had pulverized many thousand tons of coal. He stated that any figures given would have to be qualified in one way or another. The result at this meeting was that no figures on the maintenance of pulverized-coal plants were given out. Mr. Anderson's plant has probably been in operation longer than any other pulverized-coal central-station, and if its maintenance figures could not be given as worth anything no other maintenance figures from more recent pulverized-coal plants would be worth anything for comparison.

You all, no doubt, have some figure established in your minds as to the maintenance of stoker plants, and I am sorry you will have to wait to get the figures from pulverized-coal plants before you can compare them. You must remember, however, that many developments have occurred in the modern stoker to reduce labor and material maintenance. I want to tell you what is being done to reduce the maintenance of stoker plants. All stoker parts subject to renewal are so designed that the smallest amount of material and the least labor is involved in their replacement. A plate that formerly weighed from forty to fifty pounds is now designed so that the part that requires replacement is supported by the main plate, and this renewal part weighs only four or five pounds. All through the stoker, parts have been reduced in size and weight so that the least possible amount of material need be replaced, and this is replaced easily. Stoker maintenance increases when stokers are banked or when they are improperly operated; that is, more damage is done to stoker parts at these times than when the stoker is in regular operation. In research work we have applied thermometers to different parts of the structure and

*Superintendent, Compressing Stations, Equitable Gas Co., Pittsburgh.

found that these plates are relatively cool when the stoker is in regular operation. They become hot when improperly banked or when parts are allowed to remain uncovered with ash or coal. It is the belief of stoker men that they can take a particular maintenance situation where the cost of material and labor for a particular stoker has been established at a certain number of cents per ton and, by more carefully planning the method of operation, this figure can be reduced at least one-half.

Mr. E. B. Plapp:* I don't happen to be a representative of either camp. I happen to be of the group who have to distinguish between the statements of the different sides. I think we could be helped a great deal if we could know the reasons for these things.

It seems to be common knowledge that the combustion space necessary for powdered coal is considerably greater than for coal burned in a stoker. I should like to know why this is true. My idea is that in one part of the fuel bed that covers the stoker we have really a gas-producer. Then, in the other section, down farther along the stoker where most of the solid combustible is burned out of the ash, we get an excess of air which is mixed with the combustible gas coming from the other part of the fuel bed and, for the reason that both combustible and air are in gaseous form, we have a better mixing and a more rapid union of carbon and oxygen than we have in the case of powdered coal, where each solid particle itself must be acted upon by the air.

The question I should like to ask Mr. Worker concerns the curves of relative efficiencies of stokers and powdered fuel. It seems to me that these curves do not mean a great deal for the reason that unless we know the relative efficiencies of the boilers, and unless we can separate those from the efficiencies of the stokers, these curves mean nothing. Naturally, the efficiencies of the boilers would increase in the last fifteen years because we know so much more about boilers. Chief among the things we have learned are the increased use of radiant heat from the fuel bed and better use of the fuel, and not in its burning. That is no reason, it seems to me, why stokers should be more efficient than powdered-coal burners. There are certain losses from which you can not escape. Assuming that the boiler conditions are the same for both cases, these losses, we all know, are due to the

*Mechanical Engineer, United States Aluminum Co., New Kensington, Pa.

unconsumed gases and carbon; to the losses due to the hydrogen; to the moisture in the fuel; to the hot gases which must be given off from the boiler; or to boiler radiation losses. Now, I should like to ask Mr. Worker, is there any reason why the stoker should be more efficient than the powdered-coal equipment? Each side can make its statements. We have to distinguish between the two, and reasons are of value to us.

Mr. Joseph G. Worker: I understand Mr. Plapp's first question to be: Why is it necessary to use more combustion space for powdered-coal burning than for coal burned in a stoker? Fundamentally, the reason is that up to this time we do not know how to control the burning of pulverized coal. There is no definite relation between the weight of pulverized coal and its volume. It is like flour—according to moisture conditions, it might be at one time fluffy and, at another time, packed. We have heard many statements to the effect that one of the advantages of pulverized coal is the fact that combustion is easily controlled. If we stop and analyze such statements we will find that just the opposite is true. Pulverized coal is more difficult to control in its burning than lump coal, gas, oil, or any other fuel. In the first place, there is no feeder as yet designed that will feed pulverized coal into a furnace so that we know the weight of coal that is being fed. If the mechanism does not feed a given quantity, manifestly we can not control it, therefore the feeding of pulverized coal is beyond control.

As soon as the pulverized coal is actually in the furnace it is absolutely beyond control. We can not direct air to pulverized coal once it is in the furnace. If we could control pulverized coal in its feeding and in the furnace, the flame length would be five or six feet and not forty to sixty feet, thus requiring these large combustion chambers.

With stokers we have what might be called natural pulverization. The air is directed and creates a scrubbing action on the lumps of coal. The combustion air takes up its particles of carbon, but the lump of coal is always under control; that is, it does not get away when it is fed into a furnace or when it is in the furnace.

If I understand Mr. Plapp correctly, his second question is as follows: Why should the method of fuel burning on stokers be

fundamentally and theoretically more efficient in connection with the boiler than the burning of fuel in pulverized form? The reason is that the stoker transmits at least three times as much heat by radiation as is true of the fire with pulverized fuel. This means not only a better method of heat transmission to the boiler surfaces with regard to uniformity, but also means that a greater amount of the heat liberated will be absorbed by the boiler heating surfaces in the early or first stages, or passed to the boiler. The more heat absorbed in the first stage, the lower will be the temperature of the outgoing gases at the last stage; consequently, a better overall thermal result.

The very requirement of large furnace volume indicates a condition within the furnace chamber which permits very large furnace losses through improper operation, which can (and are certain to) occur over a long period of years with any process; that is, in a pulverized-fuel furnace it might be possible for all the fuel to escape up the chimney, whereas with the stoker only the volatile proportion of the fuel can actually escape unburned.

A very much larger amount of non-combustible material is carried into heating surfaces and deposited than is true with a stoker. The necessary preparation of the coal itself requires the expenditure of a large amount of energy; that is, for drying, pulverizing, transporting, and feeding.

Mr. Sydney J. McAuliffe: The question has been asked why pulverized-fuel furnaces are made larger than stoker-fired furnaces. I feel that by so doing the exponents of pulverized coal were able to gain their initial victory over the stoker adherents. Both have now found increased combustion volumes necessary to increased efficiency. That is more or less proved, to my mind, when you consider the furnace space now occupied by some of the largest stoker installations, such as Hell Gate, and compare it with recent pulverized-fuel installations.

There is a question that I have asked the leading pulverized-coal engineers of this country, and they have not been able to answer it. In Australia, with pulverized coal we have been able to burn 90,000 B.t.u. per cubic foot of furnace volume in our larger locomotives, with water-cooled walls all around the furnace and with 16 per cent. CO_2 and no CO. If such conditions can be produced in locomotives,

under the most adverse fuel-burning conditions, why can it not be done in stationary plants?

This week I was shown a most remarkable pulverized-fuel plant which I feel will startle the whole world. They are to-day actually burning over a half million B.t.u per cubic foot of combustion space, with practically no refractory loss in the furnace chambers. As the engineers responsible for it are not yet desirous of publicity, it was a very great privilege that I was shown this. It is not breaking any confidence now to announce the fact that such an installation exists. There are doubtless some engineers present who may have seen that installation, but were not advised what was going on within the furnace. In a few months, I feel confident, you will hear of one of the most startling developments yet accomplished in this field.

Mr. H. W. Brooks:* Every real debate demands an affirmative and a negative. Mr. Worker's case for the stoker is so thoroughly and comprehensively presented in his paper that there remains little to be said save on the side of the exponent of pulverized fuel. Therefore at the risk of appearing biased, when this decidedly is not the case, I take the liberty of calling your attention to a few points which a pulverized-fuel man might have made had he been with us to-night.

Permit me to preface my remarks by saying that I do not believe that pulverized coal is the panacea for all fuel-burning evils, but I do believe that it is a new tool placed in our hands as engineers so that we may develop a proper technique for its most efficient utilization. Both stokers and pulverized-fuel equipment should be applied as the doctor applies a prescription. All circumstances of the client's or the patient's condition should be taken into consideration and that prescription applied which best appears to meet the needs of the situation. I feel it our direct responsibility to ascertain speedily the proper line of demarcation between the fields for the stoker and for pulverized fuel, though I realize that the rapid developments in both fields since the World War have made the establishment of this definite line difficult, so far. Unless it is established soon, however, I fear that some concerns may be putting in pulverized coal who might find their needs better served by stokers, and similarly others who are putting in stokers should be putting in pulverized fuel. During the past week

*Fuel Engineer, Pittsburgh Experiment Station, U. S. Bureau of Mines.

I made a check of the 1923 stoker figures published by the United States Department of Commerce as compared with the installations of 1924, and there was not a single month during 1924 when the horsepower of stokers installed was as high as the corresponding month of the preceding year. Pulverized fuel is therefore making a deep impression in the fuel-burning industry. There can be no argument against that. In answer to one of the questions presented regarding the efficient burning of Pittsburgh coal on stokers, Mr. Worker has touched upon one of the peculiarly advantageous features of pulverized coal. He stated that, given the proper attitude of mind on the part of both the stoker manufacturer and user and the proper co-operative spirit, with all of the necessary refinements installed to meet the peculiarities of Pittsburgh coal, and with a proper series of experiments and possible changes which might be suggested by them, a design of stoker could probably be evolved therefrom which might burn this particular coal nearly as efficiently as the high-grade coals burned in the East. With pulverized fuel such detailed refinements would probably be unnecessary. One of the principal advantages claimed for pulverized fuel is that it permits advantage being taken of market conditions in a wide variety of coals; in fact, in numerous installations the use of gaseous, liquid, or solid fuels (either simultaneously or separately) in the same furnace without change has been proved practicable. During the period of the coal strike a year or two ago I had charge of the operation of a stoker-fired power-plant near Chicago which had been installed particularly to burn Illinois bituminous coal. It became necessary for us to purchase coal from Indiana and western Kentucky, and it is needless to describe to you the difficulties we encountered in adapting the new coal to our existing installation. With pulverized coal we probably should not have had that difficulty, for tests at Milwaukee and elsewhere indicate that pulverized-fuel equipment lends itself better to the exigencies of such occasions.

Had there been present to-night a representative of the pulverized-fuel interests he would doubtless also have claimed for pulverized fuel the following:

1. The ability to secure maximum evaporation per pound of coal under wide variations of load-factor, fuel, and other conditions.

2. The ability to maintain maximum capacity conditions over long periods.

3. The ability to meet widely varying capacity conditions with a wide variety of fuels.

4. The ability to maintain practically maximum efficiency over a wide capacity of range.

5. The ability to meet almost instantaneously any sudden peak demands without later interruption to continuous service.

6. The ability to bank over long periods with a minimum fuel loss.

The advocate of pulverized fuel claims that by the reduction of arduous manual labor the use of better men may be possible in the boiler room, thus insuring more intelligent operators. He maintains that, with pulverization to a standard fineness of 70 to 85 per cent. through a 200-mesh screen, over a billion particles of coal are produced per cubic inch of material, thus resulting in an enormously increased exposure of surface area to air and permitting combustion of small quantities of fuel at a rapid rate since there is no material in the furnace which is not actually involved in the reaction and since the quantities may be instantaneously regulated over a wide range. He maintains that refractories in pulverized-fuel furnaces, having no weight of solid material in contact, do not have the tendency to form clinkers, necessitating frequent breaking away with firing tools and consequent destruction of adjacent refractories. Again, there is little appreciable wear on the side walls due to the contact of the coal in transit.

In reply to one of the questions presented, Mr. Worker has stated that he made no comparison between pulverized-fuel operation and stoker-fired operation. I believe he has (superimposed on certain curves of pulverized-fuel tests) a derived stoker curve which he represents as present-day stoker practice. This curve, he says, is not the curve of an actual installation, but the Hell Gate and Public Service figures translated into what stoker manufacturers believe the latest stokers now under construction will do. Frankly, I do not think this is fair, nor is it ever fair to compare a theoretical curve with the curves of actual installations. If stoker manufacturers can actually produce test figures giving efficiencies of the order shown on the theoretical curve given they should be shown then, but not before then. Deduced theoretical figures of this character can only serve to harm the progress of the industry in its proper trend toward greater conservation of fuel.

One of the most telling indictments pulverized-fuel exponents have made against the stoker man has been that progress in the fuel-burning industry remained almost stationary until the advent of pulverized fuel as an accepted competitor. All too frequently stoker competition had been based on the price per pound of the cast-iron parts of which the stoker was composed. People did not begin to think about larger combustion volumes, water-cooled and air-cooled furnace walls, operation at 15 and 16 per cent. CO_2 with negligible carbon monoxid content, etc., until pulverized-fuel equipment forced the development. The stoker people have had this field pretty much to themselves for quite a number of years. Why have they not long ago availed themselves of the opportunity to bring about the efficiencies indicated on the theoretical curve which Mr. Worker now represents as modern stoker practice?

Another question presented to-night was as to why Mr. John Anderson, of Milwaukee, had answered rather vaguely at New York a question presented to him regarding his maintenance charges on a pulverized-fuel installation at Milwaukee. I do not know this to be the case but, assuming it to be true, I can well understand Mr. Anderson's position in the matter. For a number of years prior to my present connection I operated a number of boiler plants. Personally I have never been interested in plant maintenance charges during the first five years of an installation. I do not believe they mean anything. If one considers only the charges properly chargeable against maintenance during these early years and eliminates the charges for unavoidable changes incident to any new installation, the resultant maintenance figure is always ridiculously low. By definitely stating such a figure, therefore, Mr. Anderson would have placed himself in the rather embarrassing position of suggesting what would seem to many engineers to be impossibly low maintenance costs.

Another problem concerns the reason for large combustion chambers in pulverized-fuel furnaces. Offhand, I think of two reasons for this. First, the pulverized-fuel engineer, though first to recognize the necessity of proper combustion volumes, has been quickly followed in this respect by the stoker engineer who, with the present-day "super-stoker," demands combustion volumes nearly equal to those now called for in pulverized-fuel practice. Comparison of stoker installations such as Hell Gate station, the Public Service Company of New Jersey,

and others with recent pulverized-fuel installations, amply demonstrated that there is not a vast amount of difference in combustion volumes per unit of fuel burned at the present time. The second answer to this question, I believe, is that maximum engineering ingenuity has not yet been exercised by pulverized-fuel engineers in the location of their burners with respect to their furnaces so that conditions proper for the creation of maximum turbulence of flow have not yet been attained. So far, there has been little originality exhibited in the design of pulverized-fuel burners. There have been but two types, the horizontal and the vertical. In these types it has required more air to hold the coal particles in suspension for the necessary length of time for burning than has actually been required for combustion.

It happens that I also have seen the new type of pulverized-fuel furnace of which Mr. McAuliffe spoke. I know the gentleman who is making the tests on it—a former Bureau of Mines man—and, though I have made no tests personally, from his reports and from those of the chief operating engineer of one of the largest public utility syndicates in the United States under whose direction these tests are being conducted, I sincerely believe the statement that they are burning more than 500,000 B.t.u. per cubic foot of combustion volume. This, I understand, is roughly 40 times what is being done at Lakeside. A real degree of originality is being exercised in these tests. They are following out entirely new lines. It is a most interesting development which gives promise of revolutionary accomplishment. The Verein Deutscher Eisenhüttenleute, at Düsseldorf, is, I happen to know, just initiating some experiments along somewhat similar lines—the creation of turbulent flow during combustion—and it is understood that several other experiment stations both here and abroad are also conducting experiments of like character; thus there appears the possibility, and even the probability, that within a short time pulverized-fuel combustion volumes may be even less than stoker volumes. That, however, remains for the future to disclose.

In conclusion, I regret that I have been compelled to speak from what may appear to be a biased point of view in favor of pulverized coal. I should be remiss in my duties as an engineer if I failed to recognize fully the many advantages of stoker firing which have been so ably brought out by Mr. Worker. I feel that the stoker business is

a stable business and that stokers will continue to be used in their proper field of application as long as fuel is burned in solid form. I think of certain instances where I should under no circumstances recommend the application of pulverized fuel in preference to stokers. The burden of my entire plea, therefore, is that the merits and liabilities of both systems be studiously and comprehensively considered before any new installation is made, so that the final decision will be based on fact and not on exaggeration. One of the curses of any industry is the distortion or exaggeration of facts to prove the case of an interested party—a condition which I regret to say has been all too prevalent in boiler-room installations.

Mr. L. C. Frohrieb: I am quite sure that the stoker people are not altogether to blame for the small furnace volume they had to use with their stokers, for until the event of the superpower plant of recent years the purchasers of boilers refused to furnish sufficient head room in the building to allow the boiler to be placed high enough to furnish a proper amount of combustion space; the question always asked the stoker people was, on how small a combustion space can you operate?

Mr. Joseph G. Worker: I have listened with a great deal of interest to Mr. Brooks, and think I can appreciate and understand his undoubted enthusiasm for what appears to him to be a new process in fuel burning and in the conservation of our natural resources. Certainly, the most ardent advocates or representatives of pulverized fuel can not feel that they have suffered by their absence from this meeting.

Mr. Brooks stated that he made a check during the past week "of the 1923 stoker figures published by the United States Department of Commerce as compared with the installations of 1924, and there was not a single month during 1924 when the horse-power of stokers installed was as high as the corresponding month of the preceding year." From the same government reports that I presume Mr. Brooks speaks of, he will find that for the month of October, 1924, the stoker sales of the United States were 58,565 horse-power, and the sales for the corresponding period in 1923 were 32,576 horse-power. During the month of November, 1924, the sales of stokers were 37,167 horse-power, and for the month of November, 1923,

16,241 horse-power, and thus these figures show that for two months the sales of stokers in 1924 exceeded the corresponding months in 1923.

During the year 1923 there were 735,179 horse-power of water-tube boilers sold by the large boiler companies of the United States. During this same period there were 730,446 horse-power of stokers sold. Up to November, 1924, there were 414,051 horse-power of water-tube boilers sold in the United States and 482,547 horse-power of stokers, so that the sale of stokers followed very closely the sale of boilers. In fact, the sale of stokers for 1924 exceeded the reported sale of water-tube boilers.

I am in the most complete agreement with Mr. Brooks in my desire to determine as soon as possible the precise technical situation of all fuel-burning processes. Moreover, this should not be confined alone to fuel-burning processes, but to all engineering matters. I might suggest, however, that it is inevitable for people to disagree; there are two sides to every issue, and advocates will always be found on each side. There are at least two distinct sides to the issue between pulverized-fuel burning and stoker firing—one the economic, and the other the thermal. As Mr. Brooks undoubtedly well knows, hundreds of useful experimental developments on the part of the government must be curtailed because the taxpayer insists on a reduction of taxes. The taxpayer well knows that if the money is not spent, he has it. If it is spent, he may or may not get the return on it.

Mr. Brooks is quite right, in my opinion, in stating that pulverized-fuel furnaces closely resemble those employed for the burning of gaseous and liquid fuels and that they adapt themselves readily to the use of all three within the same furnace chamber. So small a percentage of the boiler horse-power of this country, however, is concerned with the combination burning of gas, liquid fuel, and solid fuel that I have left it out of consideration entirely in my paper.

Mr. Brooks recalls an experience that he had with a stoker plant which had substantial difficulties with a change in the character of the fuel which he was required to burn; and infers, from tests at Milwaukee and other places, that he would have escaped this difficulty with pulverized-fuel apparatus. As far as I have been able to learn, the stokers at Milwaukee, though many years old and now regarded

as obsolete equipment, still continue to burn precisely the same coals that are burned in the pulverized-fuel plants of that company.

I want to discuss briefly the six factors mentioned by Mr. Brooks:

1. The ability to secure maximum evaporation per pound of coal under wide variations of load factor, fuel, and other conditions.

There is no evidence as yet to indicate that the above statement is borne out by facts. Tests, generally speaking, are run at constant rating on one kind of coal, and with every possible condition established or fixed for the test period with the aid of the best instruments and appliances that can be assembled for the purpose and the most expert handling. These in no measure indicate the ability of the apparatus to attain the best conditions when operating under practical conditions with all the above-mentioned variations.

2. The ability to maintain maximum capacity conditions over long periods.

The best recent stoker plants are operating at capacities generally from 10 to 35 per cent. higher in average output than any of the best recent pulverized-fuel plants.

3. The ability to meet widely varying capacity conditions with a wide variety of fuels.

It is true that this is a claim made by the representatives of pulverized-fuel interests. So far it is unsupported in actual performance at any plant.

4. The ability to maintain practically maximum efficiency over a wide capacity of range.

None of the pulverized-fuel plants is operating over as wide a capacity range as comparable stoker plants. As nearly as I can determine, from a comparison of reported operating results and reported tests of both pulverized-fuel plants and stoker plants, the stoker plant will more nearly approach its test efficiency under actual operating conditions than will the pulverized-fuel plant. In both cases, the extent to which the test efficiency is approached is dependent on the equipment, personnel, and management of the plant.

5. The ability to meet almost instantaneously any sudden peak demands without later interruption to continuous service.

Stokers of the underfeed type have such flexibility that no demand ever placed upon them taxes their ability in this respect. It is difficult, therefore, to estimate the value of this claim, even if true.

6. The ability to bank over long periods with a minimum fuel loss.

Necessary banking losses are entirely the result of radiated heat from the boiler setting, steam-pipes, boiler tubes, etc. Any fuel burned to supply heat other than to meet this necessary loss is a waste. The amount of fuel burned under banking conditions with any device is determined entirely by the tightness of the dampers, the boiler baffles and the settings; and has nothing whatever to do with the fuel-burning process as such. It would seem reasonable to suppose, however, that because of the greater exposed surface area with pulverized fuel, the necessary losses would be somewhat greater than would be the case with the stoker.

Concerning the matter of arduous labor, it is apparent that Mr. Brooks is not familiar with the modern stoker plant as I know it. Of necessity, the pulverized-fuel plant employs more labor; mainly due to the milling of the coal. It may be true, as Mr. Brooks says, that the companies using pulverized coal have put their most intelligent labor in their pulverized-coal plant. As I have previously stated, I endeavored in my paper to make no direct comparisons between either the thermal or the economic results obtainable with stokers and pulverized coal. All of the stoker curves that I have shown are based on actual performance. Mr. Brooks must have misunderstood me, as none of the curves that I have shown is a theoretical curve. They are all based on actual test performance.

It may be true, as Mr. Brooks states, that the stoker engineer has fallen into a rut. I fail to see, however, why this should condemn the stoker as an engineering device. However, I cannot agree with Mr. Brooks on this issue. To agree with him would be to admit that John Anderson and Walker and others who have been the real stimulus behind pulverized coal were working to no purpose. I can not too forcibly remind Mr. Brooks that the issue that we are trying to get out in this case is the relative thermal and economic situation of stokers and pulverized coal. Without considering the question of where air-cooled or water-cooled walls came from, when they arrived, or who was responsible for them, certainly they are available to all engineers. Why deny the stoker the value of its economical and thermal advantage, no matter how they were evolved. While there is much to be said on the questions that Mr. Brooks raises on this point,

it is not my purpose or a part of my present paper to discuss those issues with him. I have heard from Mr. Brooks to-night the only reason that has been advanced for Mr. John Anderson's reticence on the question of maintenance; namely, "the resultant maintenance figure is ridiculously low." If Mr. Brooks's explanation is the true explanation, while I can very well understand Mr. Anderson's position or any engineer's reticence with respect to naming a figure he knows to be too low, I can not understand why he is willing to use such figures in making comparisons between two types of apparatus.

As to problematical developments, permit me to say that at the present time there are many developments in an experimental and research way with stokers which look even more promising than the experiments indicated by Mr. Brooks. It is possible that Mr. Brooks is not aware of the fact that the burning of pulverized coal under boilers has been attempted many times and in a great many different places during the past 25 years. The substantial element that has been contributed to pulverized-fuel burning during all of that time—which has represented the difference between complete failure and its present degree of success—is the use of the large furnace. As far as my knowledge goes, the type of furnace now employed for pulverized fuel in design and volume was first employed in the burning of oil.

Mr. John A. Graham:* What type of plant is giving over 500,000 B.t.u. per cubic foot of combustion space—stationary, marine, or locomotive?

Mr. Sydney J. McAuliffe: Stationary, with Springfield boilers.

Mr. L. J. Reed:† I notice that Mr. Worker obtained his hypothetical efficiency curve for the "best stoker practice" by taking efficiencies realized at different per cent. ratings with a short old-type stoker, and projecting them over as ordinates of per cent. ratings increased from the original values in proportion to the increased fuel-burning capacity of the modern stoker assumed to be installed on the same boiler. Since, apparently, he has used the equivalent of a multiplying factor based on stoker capacity, and since the original

*Superintendent of Buildings and Grounds, Shadyside Academy, Pittsburgh.
†Test Engineer, Duquesne Works, Carnegie Steel Co., Duquesne, Pa.

curve lies within the range of operation now common, the hypothetical curve not only lies beyond the range of present common operation, but extends to higher rates than we are normally using in even our most modern boiler plants. Does Mr. Worker propose taking the same boilers that formerly operated through the common range of, say, from 75 to 175 per cent. rating with the shorter stoker and running them with the modern stoker at the higher ratings of the hypothetical curve? If so, what will be the character of that curve at the lower ratings, such as the boilers will have to run at part of the time? The curve does not extend that far. In fact, it stops at the higher ratings.

It is apparent that, with an increased rate of burning fuel, the area of heating surface of the boiler per pound of coal burned, or per pound of boiler gases, is decreased. Does Mr. Worker consider that this will not change the conditions of heat absorption nor affect the efficiency of the boiler, whether or not the stoker efficiency is maintained? Aside from changes in operation made possible by such heat-recovery devices as economizers, air preheaters, air backs and water walls which Mr. Worker has so carefully analyzed, is it true that we have been running our boilers proper so far under capacity? If the boiler capacity could be increased with maintained efficiency by increasing the amount of coal efficiently burned, I should also like to ask if the same thing could not be done with powdered coal. If we were not restricted in our boiler floor space or in the height of our combustion chamber, couldn't we put in equipment to burn more pulverized coal, putting more B.t.u. into the same boiler with the same heating surface and boiler setting, except for the furnace, and, operating at the higher ratings, realize the same advantages as with the improved stoker of increased capacity?

Mr. Joseph G. Worker: Mr. Reed very properly raises a question concerning a curve I have shown. As nearly as can be told from the results obtained so far, the efficiencies at lower ratings—that is, from 50 per cent. up to boiler rating—are just as high as were obtained with the smaller stokers, as in fact they should be. In the design and operation of these stokers the working area is reduced with rating until there is actually working under the boiler only the proper relative percentage of the entire area. My only reason for not extending the curve to low rating was that it never occurred to me

that you engineers were particularly interested in these low ratings. What I have described to you is actually being done. The method by which these high efficiencies are obtained at much higher rating than was regarded as good practice in the past, involves consideration and elimination of the losses that occurred under former practice when the boiler was worked at higher than normal rates of evaporation. These losses resulted from incomplete burning of both the solid and gaseous fuel of the furnace—a large proportion of combustible discharged with the ashes; a high radiation loss; certain losses due to leakage; and other losses with which Mr. Reed is, no doubt, familiar. It is obvious, for example, that if an air-cooled wall or a water-cooled wall is employed, and, with that wall, a certain amount of heat is recovered and is put to useful work, what formerly represented a loss now represents a gain.

The combined effect of all these elements reaches a very substantial amount. For example, if two per cent. of the total heat value of the coal was formerly lost in the ashes and can now be recovered; two per cent. of the amount of heat formerly radiated from the furnace walls can now be recovered; and one-half or three-quarters of one per cent. of the heat that was lost due to moisture in the coal can now be recovered by a flue-gas dryer, it is obvious that the sum total of the items I have mentioned is four or five per cent., which is a very substantial difference and which is recovered irrespective of rate of operation and which, with careless operation, is likely to be higher rather than lower. In other words, it is four or five per cent. under the best of conditions.

Mr. L. C. Frohrieb: On this hypothetical curve that Mr. Worker showed us one stoker installation started with 200 per cent. rating. I have no doubt that it could be started at 100 per cent. rating just as well. I think that Mr. Worker explained that this efficiency was obtained by including all the refinements such as air preheating, air-cooled or water-cooled walls, economizers, soot blowers, evaporators, deep ash-pits and, above all, careful and intelligent supervision. It is not only the change in the stoker, it is the change in the entire equipment that enabled them to obtain this high efficiency.

Mr. Joseph G. Worker: None of the curves I have shown is hypothetical. As I have said before, the use of these guarantee curves

is common practice in the stoker business. The Hell Gate plant was equipped with water-cooled walls and the rotary ash discharge was made relatively deep. Most of the stokers around Pittsburgh which are equipped with a rotary ash discharge are much shallower and narrower than are being designed to-day with the modern stoker.

Mr. L. C. Frohrieb: Mr. Reed also asked whether you could not separate the stoker or the pulverized-coal tests from the boiler test. I would say offhand that this would not be very desirable, as the complete installation is under test, and not any particular part.

Mr. Joseph G. Worker: The Stoker Manufacturers' Association at one time took up this matter for discussion, and came to the conclusion that the trade would not welcome guarantees of CO^2, combustible in the ash, etc., which are elements depending on the burning of the coal on stokers. The people who purchase stokers seem to be more concerned with how many pounds of steam they can get from each pound of coal, so that this practice of making an overall evaporative guarantee is the growth of an established practice. It would be better for everyone if stoker performance could be separated from evaporative guarantees.

Mr. William Whigham, Jr.:* I should like to ask if there is any information on possible reduction of ash-pit losses in burning coke breeze. That is practically a stoker proposition, and experience seems to be that it is difficult to cut down the unburned fuel in the ash-pit. Whether that is entirely a problem of operation that will have to be worked out with each specific installation, or whether it is something that can be done with the stoker, is the question I would like to ask. Has there been any particular development along those lines? While it is not of large volume, as compared with coal-fired boilers, yet with the increase in the by-product coke industry the amount of coke being consumed under boilers is on the increase.

Mr. Joseph G. Worker: Generally, when one is purchasing a stoker to burn coke breeze, he goes about seeking a standard stoker that will burn coke breeze with a certain degree of success; and he is

*Efficiency Engineer, Clairton By-Product Coke Works, Clairton, Pa.

somewhat reluctant to spend the money that would be necessary to develop that portion of the stoker that should be particularly designed for the burning of coke breeze. By this, I mean that if the general trouble in burning coke breeze is unburned fuel in the ash-pit, this portion of the stoker should require particular attention for the given situation. Since it has been reported that $10,000 has been spent for engineering and drafting on a single pulverized-coal unit, why not spend some money on a special stoker installation to meet specific conditions? Stokers are an established product, and when we talk about particular situations we must take them out of the general situation that is covered by the 12,000,000 horse-power of stokers that I mentioned.

It is wrong to condemn an entire system because a standard product does not work satisfactorily for a special case.

I say that the stoker will do all of these specific things, such as burning coke breeze, reducing unburned coal in ash, etc., if the money and brains are put into it and the problem that must be solved is set up in advance.

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the William Penn Hotel, Tuesday, February 17, at 4:40 P. M., President W. B. Spellmire presiding, Messrs. Fohl, Ladd, Leland, Clifford, Goodspeed, Edgar, Dornbush, Clark Weldin, McDonald and the Secretary being present.

The minutes of the last regular meeting, held January 20 were approved without reading.

Applications for membership from the following gentlemen, having been published to the Society, pursuant to the action of the Board, were elected to membership:

MEMBERS

Beck, Wesley J.
Coles, Henry Taunton
Hill, Harry C.
Kline, Clement LeRoy
Lanberger, Louis Jacob
Laughner, Wm. Edward, Jr.

ASSOCIATE MEMBERS

Beatty, Hollis Strong
Beatty, John David
Cross, Harry Walter
Duensing, Heinrich F. A.
Figee, Wm. Fred
Hoover, Calvin C.
Hurtt, Wm. Tisdale
Mason, Hugh B.
Moore, Emmett Hayden
Preston, Francis Wm.
Pringle, Wm. Dick
Wolf, Frederick Nellis

JUNIORS

Bremmer, Floyd W.
Koelkebeck, Carl
Laverie, Marshall Alexander
LeCates, Raymond H.

NATIONAL SOCIETY ACCEPTANCES

MEMBERS

Benn, Charles L.
Craig, Allen B.
Humphrey, George S.
Strong, Carlton
Henderson, A. A.

ASSOCIATE MEMBERS

Bellows, S. R.
Goodwin, I. D.

ASSOCIATES

Cone, James H.
Damrau, Edw. A.
Grier, Louis N.
Herring, Thomas F.
Hill, Harold O.
Martin, F. L.
Svensson, Otto M.
VanPelt, Arthur A.

JUNIORS

Landis, Wm. C.
Manley, C. Reynolds
Peterson, John M.
Swift, Arthur D.

Applications for membership were received from the following gentlemen and their names ordered published to the Society. Assignment to the various grades of membership is as follows:

MEMBERS

Scott, J. Walter — Undercoffler, Wm. Carr

ASSOCIATE MEMBERS

Baer, Harry Louis — McKown, Harry Edwin

ASSOCIATE

Dickson, George Alexander

NATIONAL SOCIETY ACCEPTANCES

MEMBERS

Acker, Albert J. — Miller, Lyman H. — Severn, A. B.

Request for reinstatement was received from Mr. A. C. Ackenheil, and the Secretary was requested to advise him of his reinstatement to membership.

The Secretary reported the death of the following members:

	Joined	Died
G. A. Benney	June, 1918	Jan. 29, 1925
Frederic Crabtree	Mar., 1892–Jan., 1911	Feb. 14, 1925
T. O. Sullivan	Sept., 1915	Dec. 19, 1924
H. E. Whitmore	Sept., 1920	Jan. 26, 1925

Mr. Spellmire announced the death of our past president, Mr. Crabtree, and suggested that, in view of Mr. Crabtree's valuable services and faithfulness to the Society, a letter be sent to Mrs. Crabtree expressing the sympathy of the Board for her recent loss.

It was moved and carried that the Secretary be instructed to write such a letter. It was further moved and carried that the President appoint a committee to prepare a memoir of Mr. Crabtree.

The Secretary retired from the room while the election of the Secretary took place. K. F. Treschow was re-elected Secretary for the coming year.

The report of the Secretary showing the financial condition of the Society at the close of business January 31, having been audited by the Finance Committee, was approved.

Mr. Clifford, chairman of the Entertainment Committee, reported that he had reappointed the members of last year's committee with the addition of Mr. H. E. Cole. He further reported that he was glad to announce that the banquet had been one of the most successful in the history of the Society and that a final check up of expenditures and receipts showed a net profit of about $38.

Mr. Fohl, chairman of the Finance Committee, reported that he had reappointed the members of the committee who served last year and that a meeting of the committee had been held Monday, February 16, at which time the general financial condition of the Society had been discussed and the following budget of expenditures and receipts for 1925 made up for the approval of the Board at this meeting:

Estimated Expenditures

Rent	$ 6,000.00
Salaries	8,340.00
Year Book	600.00
Miscellaneous Printing	1,400.00
Postage	800.00
Advertising Solicitor	270.90
Office and Miscellaneous	1,200.00
Entertainment Committee	1,000.00
Reporting	450.00
Auditing	225.00
Society Pins	150.00
	$20,435.90

Receipts

Membership:		
Members—Resident	1,011	$15,165.00
Non-Resident	220	2,200.00
Associate Members—Resident	129	1,935.00
Non-Resident	9	90.00
Associates—Resident	54	675.00
Non-Resident	5	37.50
Juniors—Resident	85	850.00
Non-Resident	12	90.00
Student Juniors—Resident	3	9.00
Non-Resident	....	....
	1,528	$21,051.50
Sales of PROCEEDINGS		600.00
Interest		900.00
Society Pins		150.00
		$22,701.50

Mr. Fohl then called attention to the fact that these budgets had been made up after a careful study of our last year's budget and that the committee thought that they were both drawn up on a conservative basis.

Attention was called to the fact that all of the items, with the exception of salaries and Entertainment Committee, remain practically the same as last year, with the exception of rent, which, of course, was increased due to the taking on of the Hawaiian Room. Addition in salaries is caused by an increase of $5 per week for the young man keeping the rooms open in the evening and $10 per month for the assistant in the office, which the committee hereby recommends. The addition to the Entertainment Committee appropriation is made as it was found the amount allotted last year of $500 was not sufficient to allow the committee to carry on the necessary activities, and it was felt that additional allowance should be made in order that they might continue the work started last year.

After a general discussion it was moved and carried that the increased budget as recommended by the committee be adopted.

Mr. Fohl further stated that there were three other items which the committee had considered, viz., the purchasing of two new coat racks, two new typewriters, and a drinking fountain for use in the Club Room, at a total cost of $382. The Finance Committee wished to recommend to the Board that the chairman be authorized to make these purchases at such time as may seem advisable.

It was moved and carried that the chairman of the Finance Committee be authorized to purchase the items mentioned above at a cost not exceeding $382.

Mr. Fohl also called attention to the fact that in making up the 1925 budget the committee had budgeted the PROCEEDINGS separately. Inasmuch as we now have our publications on a self-supporting basis, due to the advertising, it was felt that this expenditure should be kept separate. The following budget was therefore recommended for the publication of 1925 PROCEEDINGS:

ESTIMATED PROCEEDINGS EXPENDITURES

Printing	$4,000.00
Postage	250.00
Editorial Expense	450.00
Cuts	400.00
Expressage	30.00
	$5,130.00

ESTIMATED PROCEEDINGS RECEIPTS

Receipts	$5,300.00

After discussion it was moved and carried that the recommendation of the committee be approved and that in the future the expenditures and receipts for PROCEEDINGS be figured separately.

Mr. Leland, chairman of the House Committee, reported that he had reappointed Mr. L. C. Frohrieb and Mr. William F. Hall as members of his committee for the coming year. The evening attendance for the month of January was 420.

In the absence of Mr. Affelder, chairman of the Membership Committee, the Secretary reported that the following gentlemen had been appointed to serve on his committee for the coming year:

W. P. Chandler	J. S. Fulton	T. H. Ross
C. G. Bigelow	G. W. Quentin	W. B. Skinkle
Lane Johnson	E. Rahm, Jr.	G. E. Stoltz

Mr. Goodspeed, chairman of the Publication Committee, reported that he had appointed the following gentlemen to serve on his committee for the year:

N. G. Alford	H. L. Beach	L. C. Edgar
N. Allderdice	Sydney Dillon	C. H. Clark
J. B. Crane	J. Kennedy, Jr.	H. H. Rankin
E. R. Weidlein	C. C. Dornbush	

It was moved and carried that the committees as appointed by the various chairmen be approved.

The Secretary read a letter from Mr. E. M. Tate, Secretary of the Pittsburgh Builders' Exchange, urging our Society to endorse a resolution adopted by their Board of Direction, which calls attention to the fact that they wish to go on record as opposing the selection of out-of-town architects, engineers or contractors for the designing, erection and construction of buildings in this city.

After discussion it was moved and carried that this matter be tabled.

Mr. Spellmire reported that a meeting of the Governing Council of the Associated Engineering Societies of Pittsburgh had been held Tuesday, February 3, to consider a bill presented in the House of Representatives on December 8, being an amendment to the present General Bridge Act of the United States. Mr. Spellmire stated that this bill had geen called to his attention by several members of the Associated Societies, who considered it detrimental to the interests of the country.

The Governing Council, after carefully considering the bill, had decided that the matter was a national rather than a local one, and, therefore, should be taken up by the American Engineering Council, and had instructed the Secretary to write the Council calling their attention to the bill and asking that they investigate it. Mr. Spellmire reported further that the Secretary had written this letter with the result that the American Engineering Council Secretary had replied to the effect that they had alrady investigated the measure and felt sure there was no possibility of action being taken during the present session of Congress and, therefore, it appeared better to wait until the bill was again introduced before making further investigation.

The meeting adjourned at 6:15 P. M.

K. F. Treschow, *Secretary.*

MECHANICAL SECTION

The annual meeting of the Mechanical Section of the Engineers' Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Monday evening, February 2, at 8:15 o'clock, Chairman W. C. Buell presiding, 41 members and visitors being present.

The minutes of the last annual meeting were read and approved.

The annual report of the Section was read by the Secretary.

The report of the Nominating Committee was read by Mr. L. W. Heller, chairman, as follows:

To Members and Officers, Mechanical Section:

Dear Sirs—Your Nominating Committee appointed to nominate officers for the Mechanical Section for the ensuing year held a meeting Saturday, January 31, and made the following nominations:

C. H. Clark.......................Chairman
E. J. Deckman.......................Vice Chairman

H. W. Brooks
J. S. Fulton
K. W. Gass
R. E. Polk
Wm. Shaw
} ....Directors

Respectfully submitted,

L. W. Heller, Chairman,
J. B. Crane,
Van A. Reed,
Nominating Committee.

On motion, the nominations were closed and the Secretary instructed to cast a unanimous ballot in favor of the officers named, who were thereupon declared elected.

There being no further business, the meeting adjourned and the regular bi-monthly meeting was called to order by the new chairman.

The address of the retiring chairman was then presented by Mr. W. C. Buell, on "Some Aspects of Oxygen Enrichment of Combustion Air in Heating Furnace Practice."

Written discussion was presented by: W. P. Chandler, Jr., Asst. Fuel Expr. Engr., Carnegie Steel Company; A. E. Blake, Pittsburgh Repr., U. G. I. Contracting Co. of Philadelphia.

The ensuing discussion was participated in by: H. W. Brooks, Fuel Engr., U. S. Bureau of Mines; G. M. Comstock, Surface Combustion Co.; E. J. Stephany, Supt., Sales Dept., Equitable Gas Co.; C. S. Palmer, Chemical Engr., Pittsburgh, Pa.; J. S Unger, Mgr., Research Bureau, Carnegie Steel Co.; and the author.

On motion, duly seconded and carried, a vote of thanks was extended to Mr. Buell for his very interesting paper.

On motion, the meeting adjourned at 9:40 P. M.

K. F. TRESCHOW, *Secretary.*

REGULAR MONTHLY MEETING

The 428th regular monthly meeting of the Engineers' Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Tuesday evening, February 17, at 8:23 o'clock. President W. B. Spellmire presiding, 53 members and visitors being present.

The minutes of the last regular meeting, held December 9, were read and approved.

The Board of Direction reported the election of eleven membrs to the grade of Member, fourteen to the grade of Associate Member, eight to the grade of Associate and eight to the grade of Junior, and the receipt of eight applications for membership. There was one reinstatement and three deaths reported.

No further business coming before the Society, the paper of the evening, on "Modern Excavating Machinery," was presented by Mr. W. W. Goetz, Electrical Engineer, Bucyrus Company, South Milwaukee, Wis., in the absence of the author, Mr. G. A. Morrison, Second Vice President of the above company.

The ensuing discussion was participated in by: W. B. Spellmire, Mgr., General Electric Co.; H. L. Beach, Professional Engineer; F. B. Smith, Sales Repr., Bucyrus Co.; G. White, White Clay Mine Co., F. W. Henrici, Asst. Engr., Erecting Dept., American Bridge Co.; F. A. McDonald, Gen. Supt. & Chf. Engr., National Mining Co.; G. P. Thomas, Pres., Thomas Spacing Machine Co.; F. E. Cash, U. S. Bureau of Mines.

On motion, duly seconded and approved, a vote of thanks was extended to Mr. Goetz for his very interesting talk.

The meeting adjourned at 10 P. M.

K. F. TRESCHOW, *Secretary.*

MINING SECTION

The annual meeting of the Mining Section of the Engineers' Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Tuesday, February 24, at 8:14 P. M., Chairman R. A. McDonald presiding, 66 members and visitors being present.

The minutes of the last annual meeting were read and approved.

The annual report of the Section was read by the Secretary.

The report of the Nominating Committee was read by Mr. Bright, chairman, as follows:

To Members and Officers, Mining Section:

DEAR SIRS—Your Nominating Committee held a meeting to nominate officers for the ensuing year, and the following members were appointed:

N. G. Alford .... Chairman
N. F. Hopkins .... Vice Chairman
R. M. Black
R. W. McCasland
M. D. Gibson .... Directors
T. G. Fear
H. R. Miller

Respectfully submitted,

GRAHAM BRIGHT, Chairman,
S. L. GOODALE,
Nominating Committee.

On motion, the nominations were closed and the Secretary was instructed to cast a unanimous ballot in favor of the officers named, and they were thereupon declared elected.

No further business coming before the Section, the meeting adjourned and the regular meeting called to order by the new chairman.

The paper of the evening was presented by Mr. C. E. H. VonSothen, Engineer, General Electric Co., Schenectady, N. Y.

The ensuing discussion was participated in by: F. A. McDonald, Supt. & Chf. Engr., National Mining Co.; G. G. Lail, Engr., Pittsburgh Office, General Electric Co.; J. P. Toler, Mech. Engr., Pittsburgh Limestone Co.; Graham Bright, Cons. Engr., Howard N. Eavenson & Associates; R. R. Owen, Switchboard Specialist, General Electric Co.; Walker Anderson, Control Specialist, General Electric Co.; W. S. Sprengle, Automatic Reclosing Circuit Breaker Co.; E. W. Brown, Mgr., Coal Mining Div., Westinghouse Elec. & Mfg. Co.; G. R. K. Day, Quotation Division, General Electric Co.; G. E. Graham, H. C. Frick Coke Co.; J. Bryan, Industrial Div., General Electric Co.; A. E. Anderson, H. C. Frick Coke Co.; and the author.

On motion, duly seconded and carried, a vote of thanks was extended to Mr. VonSothen for his very interesting paper.

On motion, the meeting adjourned at 10:10 P. M.

K. F. TRESCHOW, *Secretary.*

THE BRIDGE-RAISING PROGRAM ON THE ALLEGHENY RIVER IN ALLEGHENY COUNTY*

By V. R. Covell†

OUTLINE

Our Navigable Streams.
Existing Bridges Deemed Obstructions to Navigation.
Contest over Alteration Order.
Approval Bodies.
Design of Bridges.
The Bridges in Detail.

OUR NAVIGABLE STREAMS

A child, just beginning to grasp the meaning of geography, remarked, "Isn't it strange that there is always a river or large body of water near every city?" We may have noticed this same condition, but it has given us an impression quite different from the one given the child. We realized that the presence of the navigable water, with its many advantages, has attracted the settlers and industries which have produced our great cities. Some of our communities are confronted with the serious question of ample water-supply, the lack of which is sure to limit their growth.

Necessity for Bridges. Pittsburgh and Allegheny County are admirably supplied with water, but at a great cost in the necessary construction and maintenance of bridges, in order that uninterrupted communication may be maintained. Within the confines of the county there are 31 highway bridges and 18 steam railroad bridges over main or back channels of our four rivers, a condition which means a large outlay in first cost and maintenance of these structures. The change from ferry, with all its attendant dangers and inconvenience, to more or less expensive bridges, came early in the history of the community. These first bridges were the result of private enterprise and were supported by the tolls paid by those who used them. In passing, it should be said that the toll-bridge system is undoubtedly

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†County Engineer, Bureau of Bridges, Department of Public Works, Allegheny County.

more equitable in the distribution of maintenance cost than free bridges. Those who profit in convenience or commercial gain pay the cost of the utility; but modern thought is adverse to toll-bridges as well as to toll roads; it is an unpopular method of collecting taxes.

Control by the United States War Department. While the navigability of the Allegheny River was always under control of the United States War Department, little thought seems to have been given in earlier years to any interference which bridges might offer to navigation. Prior to the introduction of modern methods of bridge construction, all river spans were limited to comparatively short lengths, and the somewhat scant clearance was further reduced by the riprap around the piers, made necessary by the shallow depths of foundations then in use. As it was, the projects were large enough to tax the available resources, without any attempt at long spans. This was especially true on the Allegheny River, where the comparatively swift current and lack of slack water made the requirements for clearance of secondary importance. The last highway bridge constructed over the Allegheny River within the limits of the county, which did not meet the present-day requirements of the United States War Department, was built at Sixth Street in 1892.

River and Harbor Act of 1899. The River and Harbor Act of March 3, 1899, provided that:

> "Whenever the Secretary of War shall have good reason to believe that any railroad or other bridge now constructed, or which may hereafter be constructed, over any of the navigable waterways of the United States, is an unreasonable obstruction to the free navigation of such waters on account of insufficient height, width of span, or otherwise . . . it shall be the duty of the said Secretary, first giving the parties reasonable opportunity to be heard, to give notice to the persons or corporations owning or controlling such bridge, so to alter the same as to render navigation through or under it reasonably free, easy and unobstructed; and in giving such notice he shall specify the changes recommended by the Chief of Engineers that are required to be made, and shall prescribe in each case a reasonable time in which to make them."

The Manchester, Sixteenth Street, Fortieth Street, Sixty-second Street, Highland Park, Oakmont, and New Kensington bridges, all built since this enactment, meet the present requirements of the War Department both as to clear height and span.

EXISTING BRIDGES DEEMED OBSTRUCTIONS TO NAVIGATION

During 1902 the six highway bridges, then located at Sixth Street, Seventh Street, Ninth Street, Sixteenth Street, Thirtieth Street and Forty-third Street, owned by private companies, and the Ft. Wayne Railroad bridge, were made the subject of attack on the grounds that they were "unreasonable obstructions to the free navigation" of the Allegheny River.

Decision of Secretary Root and Secretary Taft. Hearings were held before Captain (now General) W. L. Sibert; the initial formal complaint being made March 13, 1903; and on January 23, 1904, Hon. Elihu Root, Secretary of War, denied the applications for alterations in the bridges. Again, on February 26, 1908, Hon. William H. Taft, Secretary of War, refused to order similar charges prayed for in a second petition.

Report of Board of Engineer Officers, 1909. Later, a Board of Engineer Officers, composed of Brigadier General W. H. Bixby, Colonel William T. Rossell and Colonel C. McD. Townsend, was constituted by order issued June 9, 1909. A report, in part, from this Board is as follows:

> "The conclusions of the Board are that the bridges spanning the Allegheny River under consideration from the Sixth Street to the Forty-third Street bridge, inclusive, as they now exist, are unreasonable obstructions to navigation and such as to hinder the growth of river commerce."

Decision of Secretary Dickinson and Freeing of Bridges, 1911. This Board had been appointed by Hon. Luke E. Wright while Secretary of War, but the report was filed during the incumbency of Hon. J. M. Dickinson, as Secretary of War, who on March 6, 1911, denied the prayer of the petitioners and overruled the conclusions of the Board. It was then thought that the question of alteration of these bridges, in the interest of navigation, was settled during the life of the bridges, and on March 16, 1911, immediately following this decision, the County Commissioners took possession of and freed five of these highway bridges, and included the remaining bridge at Forty-third Street on June 8, 1912. The question of the alteration of the bridges was thus transferred from private interest to that of the taxpayers of the county.

Report of Lieutenant Colonel Shunk, 1916. The change of administration at Washington in 1913 was taken as an opportunity for

reopening this question and the matter was brought to the attention of Hon. Lindley H. Garrison, Secretary of War, with a public hearing on December 2, 1915. Under date of June 19, 1916, Lieutenant Colonel Shunk, Corps of Engineers, submitted his report to Hon. Newton D. Baker, then Secretary of War, recommending for each bridge three spans, with the central span having a clear height above Davis Island pool, elevation 703, as shown in the following table, which also gives the clear heights of the bridges as they then existed, and the amount of change deemed necessary:

	Recommended height in feet	Existing height in feet	Additional height in feet
Sixth Street bridge	43.0	33.4	9.6
Seventh Street bridge	43.1	35.0	8.1
Ninth Street bridge	43.3	33.6	9.7
Sixteenth Street bridge	44.2	31.9	12.3
*Thirtieth Street bridge	47.0	36.0	11.0
*Forty-third Street bridge	47.0	27.7	19.3

To this nominal additional height must be added the increased depth of floor.

Order of Secretary Baker, 1917. In the pamphlet dated March 23, 1917, giving the "Opinion of the Secretary of War," the whole question is reviewed, and the matter is summed up with three conclusions:

> "The bridges in question are an unreasonable obstruction to navigation of the Allegheny River.
>
> Their immediate elevation and the relocation of their piers is necessary in the national interest.
>
> The improvements ought to be undertaken in such an order as to make the inconvenience to the people of Pittsburgh during their progress the least possible."

Secretary Baker issued orders, received by the County Commissioners, March 28, 1917, making in part the following requirements:

Bridge	Height required above Davis Island pool	Work to commence	Work to be completed
Sixth Street bridge	47.0	Sept. 28, 1919	Sept. 28, 1921
Seventh Street bridge	47.1	Sept. 28, 1918	Sept. 28, 1920
Ninth Street bridge	47.3	Sept. 28, 1918	Sept. 28, 1920
Sixteenth Street bridge	48.2	Mar. 28, 1917	Mar. 28, 1919
*Thirtieth Street bridge	51.0	Mar. 28, 1920	Mar. 28, 1922
*Forty-third Street bridge	51.0	Mar. 28, 1917	Mar. 28, 1919

*In Herrs Island pool.

This meant the tearing down and rebuilding of all of these bridges; the masonry and superstructures could not be embodied in the new structures.

Before the work of alteration was under way we were in the World War, and the order was suspended in March, 1918. On April 23, 1918, the Sixteenth Street bridge was mysteriously destroyed by fire and shortly afterwards the debris and piers were removed. On April 2, 1919, the County Commissioners received revised orders which changed the dates for the remaining bridges as follows:

Bridge	Work to commence	Work to be completed
Sixth Street bridge	April 2, 1921	April 2, 1923
Seventh Street bridge	April 2, 1920	April 2, 1922
Ninth Street bridge	April 2, 1920	April 2, 1922
Thirtieth Street bridge	April 2, 1922	April 2, 1924
Forty-third Street bridge	April 2, 1919	April 2, 1921

History of Union and Other Bridge Cases. Three other bridges on the rivers under the jurisdiction of the United States Engineer Office at Pittsburgh were the subject of action under the Act of Congress of March 3, 1899. The Secretary of War served notice on the Union Bridge Company, January 26, 1903, to alter its bridge—a covered, wooden, Burr truss located at the site of the present Manchester bridge over the mouth of the Allegheny River. Upon request of the Company the time was extended to January 1, 1905. A rehearing was refused June 21, 1905, and action later taken in the District Court of the United States for Western Pennsylvania. The defendant was found guilty and fined. The Supreme Court sustained the lower court in a decision filed February 25, 1907, and the work of removal was completed in February, 1908. A similar proceeding was had in the case of the Brownsville bridge over the Monongahela River, the case also being carried to the Supreme Court. The notice was served August 15, 1904, and the work of removal was started late in 1910. The bridge over the Monongahela River at Monongahela City was made free by Allegheny and Washington counties, April 3, 1906; and, under date of October 10 of the same year, the Commissioners of the two counties were ordered to alter this bridge. The present bridge was built in 1909 about 1000 feet below the old bridge and the latter was removed in 1910; thus there was an abundance of precedent as to what might be expected in the cases of these other river bridges.

CONTEST OVER ALTERATION ORDER

Bond Election of 1921. Following these orders there were numerous conferences and many studies of the conditions necessary to meet their requirements. Matters had developed to a sufficient extent so that the People's Bond Issue submitted to the electors November 8, 1921, carried an item of $3,500,000 for rebuilding the three downtown bridges, but this item, with all the others, was defeated.

Desirable Grades. The proposed clearance height at the Sixteenth Street, Thirtieth Street and Forty-third Street bridges presented no serious difficulty. Local conditions and the necessity of eliminating grade crossings compelled the placing of the roadway at ample height to give the prescribed clearance for navigation. With the three down-town bridges, however, the conditions were quite different. Undesirable grades on the approaches and on the bridges themselves, or the raising of the street grades at a great cost to the City or County, were necessary to meet the requirement of the order of the Secretary of War. The additional four feet ordered by Secretary Baker, above that recommended by Lieutenant Colonel Shunk, was a serious matter. It meant heavy cost for construction and large damages due to the changes of grade, or an increase of about one per cent. in the grades on the bridge structures.

Bridge Raising Board of 1922. It was deemed very desirable that the grades on the floors of the bridges should not exceed three per cent., and there was hope on the part of some, who were deeply interested in this matter, that, with still another change of administration at Washington, it would be possible to secure a modification in the order, at least in so far as it applied to the three down-town bridges, so that the clearance recommended by Lieutenant Colonel Shunk would be deemed sufficient. A conference was held with the Secretary of War at Washington, November 17, 1921, but without favorable results so far as any change was concerned. In April, 1922, pursuant to an agreement reached by the County Commissioners, the Mayor of Pittsburgh and General Lansing H. Beach, Chief of Corps of Engineers, a Bridge Raising Board was appointed, with J. G. Chalfant, County Engineer, representing the County; Charles A. Finley, Director of the Department of Public Works, representing the City; and Major J. Franklin Bell, Corps Engineer, representing the United States War Department.

After several meetings, this Board presented its report on the Sixth Street and Ninth Street bridges on May 11, 1922, and a separate report on the Seventh Street bridge on May 20, 1922. These reports were predicated upon the opposition on the part of the City to any radical changes in street grades and to lack of willingness on the part of the War Department to modify its orders. It was recommended that the Sixth Street bridge be rebuilt without change of grade in the approaches and with a maximum grade on the bridge of 4.25 per cent.; that the Ninth Street bridge be rebuilt with a raise of grade on Ninth Street at Duquesne Way of 2.63 feet, and with a maximum grade on the structure of 4.5 per cent. Consideration was given to the possibility of doing away with the Seventh Street bridge, but the second report recommended that this bridge be rebuilt with a raise in the grade on Seventh Street at Duquesne Way of 4.36 feet and with a maximum grade on the structure of 4.5 per cent. At the request of the County Commissioners, made on August 14, 1922, this Board—with the writer substituted for J. G. Chalfant, then ill—reported that it could not make a unanimous report in regard to the height to which the bridges should be raised, but that Messrs. Finley and Covell were of the opinion that the requirements of the War Department, as to heights, should be modified.

Meeting at Washington, 1922. A meeting of the County Commissioners and others, with the Secretary of War, J. W. Weeks, was held at Washington on October 21, 1922, at which time an effort was made to have the case reopened to admit new evidence in the hope of securing modification of the orders. Secretary Weeks quoted from former Secretary Taft's ruling, that where an order of the War Department involved equity, the case would not be reopened unless new evidence were produced. We were unable to convince him that we had sufficient new evidence to warrant a hearing, and from that time there has been no question as to the clear height that must be given in designing these bridges.

Continuous-Traffic Lift Bridges. During the early part of 1922, Mr. A. A. Henderson, Assistant Engineer in the County Engineer's office, developed the idea of "continuous-traffic lift bridges" for these three down-town bridge sites, and described his idea before this Society in a paper which was published in the July number of the PROCEEDINGS for 1922. The adoption of Mr. Henderson's plan

would have made it possible to hold the bridges at a grade not to exceed the desired three per cent. for all but about thirty days in the average year and with the necessity of exceeding five per cent. for about six days in the year. There seemed to be many advantages to be secured by this method of meeting the requirements of the navigation interests. The bridges could be raised or lowered slowly, holding to a minimum clearance above water at all times, and for about eleven months in the average year the grades of the bridge would be so easy as to offer no difficulty for any kind of traffic.

Application to War Department. February 28, 1923, plans were submitted by the County Commissioners to the Secretary of War for permits for bridges at Seventh, Ninth and Thirty-first Streets, giving (1) a design drawn in accordance with the order of the War Department; (2) a design for the Seventh Street and Ninth Street bridges, using the continuous-traffic lift bridge scheme. With the latter, there was given a somewhat exhaustive argument in its favor. In a conference between General Beach, Major Bell, County Commissioner Addison C. Gumbert and others, on April 9, 1923, General Beach expressed his unwillingness to recommend the continuous-traffic lift type for so important a place, as he considered that because it was untried it would be more or less an experiment. When the permits were issued they were for the fixed type of bridges and the controversy over the method of meeting the required clearance height seemed to be at an end.

APPROVAL BODIES

At this point it may be interesting to note that there are various other bodies, outside the War Department, which must be taken into consideration in the design and construction of a bridge over navigable rivers in the City of Pittsburgh. In the cases where there has been no order from the Secretary of War, acting under the before-mentioned Act of Congress, requiring the rebuilding of the bridge, there must be an Act of Congress. Before the Secretary of War will issue a permit, he must be satisfied that the Water and Power Resources Board of the Commonwealth of Pennsylvania has given its approval. Plans in considerable detail must be presented to the Grand Jury and the Court of Quarter Sessions for consideration and approval. The Flood Commission of Pittsburgh must be consulted to determine whether any part of the structure will interfere with future plans for flood control.

The Department of City Planning, the Citizens' Committee on City Plan and the County Planning Commission have all to be consulted in working out the grades, general plans and connections. The design must be submitted to the city Art Commission for consideration and approval. Consent and grade ordinances should be passed by the City Council, and, in the case of the Fortieth Street bridge, by Millvale Borough Council as well. Clearance and pier locations must be taken up and adjusted with railroads, and when the interests of any public utilities are involved the matter must be brought before the Public Service Commission and its approval secured. This Commission must also approve any agreements made with public-utility companies. It is possible that the change required by one approval body may require resubmission to another that has already acted. The Water and Power Resources Board is chiefly interested in the maintenance of the requisite cross-section of the watercourse, without special regard to the location of piers; while the War Department is concerned mainly in such a design as to give the best possible facilities for the navigation of the stream, regardless of other conditions; and, in arriving at its conclusions, the opinions of the members of the Pittsburgh Coal Exchange are necessarily given much weight. The navigation interests are concerned not only with the vertical and horizontal clearances, but also with the skew of the piers and their position in relation to those of adjacent bridges; and the necessity of shifting piers to meet these various requirements makes difficult the design and construction within reasonable cost limits. The requirements of the Art Commission, in the interest of beauty and of harmony with the surroundings, rules out types of bridges which would be used if utility and economy only were to be considered. The many helpful suggestions of the planning bodies are often so tied up with other needed improvements that there is delay in reaching a satisfactory conclusion. I may have omitted some of the approval bodies, but I have named enough to give some idea of the routine which must be followed to get such a bridge under contract.

DESIGN OF BRIDGES

Selection of Architects. As soon as it was known that six new bridges over the Allegheny River were to be built out of public funds, interested civic bodies urged upon the County Commissioners the importance of building beautiful as well as useful bridges; and, to this

end, a request was made that the work of design should be placed in the hands of architects. This program was carried out in the case of two of the bridges by commissioning Warren & Wetmore, of New York, with H. G. Balcom as associate engineer, to design and erect the new Sixteenth Street bridge; and Benno Janssen, of Pittsburgh, with C. S. Davis as associate engineer, to design and construct the Fortieth Street bridge. This decision brought out some sharp criticism on the part of engineers as to the justice of placing in the hands of architects work based predominantly on engineering principles.

Organization of Department of Public Works. Before a final decision was reached for the remaining bridges, the new Department of Public Works of Allegheny County was organized with an efficient architectural force which co-operates with the Bureau of Bridges in all bridge designs, and the occasion for securing outside architectural help no longer exists.

THE BRIDGES IN DETAIL

Sixteenth Street Bridge. Taking up the bridges briefly, in the order in which they are being constructed, the Sixteenth Street bridge comes first for consideration. The structure which was the subject of the removal order was a covered, wooden, Burr truss erected in 1866 on masonry which was constructed in 1837. This masonry had carried two former bridges of similar type, one of which—like the last—was burned, and the other destroyed by flood. The new bridge consists of three river spans having the structural features of two-hinged, latticed arches with the thrust taken by horizontal ties at the floor level. The approach spans consist of deck plate-girders, carried on three lines of columns. There are two 10-foot sidewalks and the roadway has a clear width of 38 feet, and is designed to carry street-car tracks, which are now being placed by the Pittsburgh Railways Company. The approaches are raised to give clearance over the tracks of the Baltimore & Ohio Railroad on the north side, and over a further extension of yard tracks of the Pennsylvania Railroad on the south side. The masonry is faced with Beaver valley sandstone, and the river piers were carried to rock by the pneumatic process. The river piers are defined by stone pylons arched over the sidewalks and supporting bronze allegorical groups. The solution of the problem, when the limitations of the site are considered, has much in its favor. The original design, which called for true arches with a springing-line

below the level of the present floor, encroached too much upon the waterway to be permitted. The hangers which support the roadway offer comparatively little obstruction to the view, which is one very desirable feature of this type of construction. The contracts were awarded in September, 1921, and the bridge was formally opened for traffic October 9, 1923. The total cost of the bridge, exclusive of property damages, was $1,292,862.88, and the total damages awarded amounted to $321,201.50, making a grand total of $1,614,064.38.

Fortieth Street Bridge. The Forty-third Street bridge was built in 1870 and consisted of four spans of covered, wooden, Burr trusses supported on sandstone masonry. There were grade crossings of the tracks of the Pennsylvania and the Baltimore & Ohio railroads at both the Pittsburgh and Millvale ends—a source of many vexatious delays, as well as of great danger. Careful study of the situation led to the selection of a site, starting at Fortieth and Foster Streets in Pittsburgh and extending through a corner of the United States Arsenal property, over the tracks of both railroads on both sides of the river and landing on a new location of Ohio Street on the hillside in Millvale. At the Millvale side it was necessary to give sufficient clearance so that the bridge would clear the tracks of the Baltimore & Ohio Railroad, which, in turn, were to be raised to clear the tracks of the Pennsylvania Railroad. This gave such liberal head room over the river that it was feasible to design a bridge with three deck steel-girder arch spans over the river and deck plate-girder approach spans. The result is one of the most pleasing outlines of any of our bridges. The contracts for the superstructure, Millvale approach, paving on the superstructure, and electrical work were let in December, 1922, and the contract for the masonry and ornamental work in February, 1923. The bridge was sufficiently completed so that it was thrown open to vehicular traffic on December 29, 1924, though some of the sidewalk construction and the plaza and approach paving at the Pittsburgh end remain uncompleted. The total cost of the structure, including damages, is estimated at $2,880,000. The Pennsylvania Railroad and the Baltimore & Ohio Railroad, jointly, contributed $300,000 toward the cost of the bridge as their share of the cost of the elimination of the grade crossings; and the Pittsburgh Railways Company contributed $10,000 toward the cost of the track foundation on the Millvale approach, thus making the net estimated cost to Alle-

gheny County $2,570,000. Owing to the historical significance of the site of this bridge, due to the perilous crossing of the river at this point by George Washington on December 29, 1753, the bridge has been named "Washington Crossing." Each end of the structure is defined by a pair of granite obelisks and the shore piers are emphasized by means of large concrete pylons. The steel throughout had a copper content of from 0.18 to 0.28 per cent. to increase its resistance to corrosion. The new right of way in Millvale necessitated the moving or tearing down of some thirty-five residences or business buildings. The bridge has a 38-foot clear roadway and two eight-foot sidewalks, and is designed to carry street-cars when it becomes desirable.

At the time the bridge was taken over by the County the trusses of the old bridge at Forty-third Street had been forced up-stream, out of plumb, by the prevailing westwardly winds, but the excessively high wind of July 1, 1922, increased this movement so much that the roof and siding were removed and steel portals added to insure its continued use until the new bridge was completed. During 1924, steel cables were added to assist in maintaining the alignment, and all solid-tired trucks were excluded. During the last few months of its use readings were taken every week to check any possible increase in the lateral movement of the bridge, which is now being torn down.

Sixth Street, Seventh Street, and Ninth Street Bridges. The three down-town bridges, located within a few hundred feet of each other, form a group which will be considered together. The elevations of the streets which form the approaches to these bridges, and the requirements of the alteration orders, were so nearly identical that the solution of the problem for one readily pointed the way to the solution in the case of the others. Owing to the progress that had been made on the Sixteenth Street and Fortieth Street bridges, and the comparative unimportance of the situation at Thirtieth Street, the three down-town bridges were now the storm-center of the bridge-raising discussion.

Meeting With General Beach, 1924. The new Department of Public Works had been organized, and on March 12, 1924, a conference between General Lansing H. Beach, Major E. L. Daley and Major T. B. Larkin, representing the United States government; and the County Commissioners, Director Norman F. Brown and others, representing the County, was held in Major Daley's office, in

Pittsburgh, to discuss the rebuilding program for the remaining four bridges. The Commissioners gave assurance that all possible effort would be made to complete the program promptly, and expressed the belief that the bond issue, then before the people, would be approved (as eventuated on April 22), but stated their willingness to exhaust their own bonding power to do this work if the vote of the people should be adverse. A request was made that the petitions, which would in all probability be presented to the Secretary of War in the near future for permits for the Point bridge, Liberty bridge and other river bridges, should be favorably considered. General Beach called attention to the Act of Congress which provided that the contemplated locks and dams in the Allegheny River should not proceed until the Secretary of War had reasonable assurance that his order in regard to rebuilding the bridges over the river in Pittsburgh would be complied with. He further stated that reasonable assurance meant that contracts must be awarded for both the substructures and the superstructures of the three down-town bridges, so that there could be no drawing back on the part of the present or future boards of Commissioners. It was urged that the Ninth Street bridge should be allowed to stand until the Seventh Street bridge was completed, but General Beach responded by suggesting that the old bridge could be raised and the new one built around it, thus keeping travel going. A development showed that the location of the new piers, with reference to the old ones, made this method of procedure impossible. The result of the meeting was that in order to release the funds for the improvement of the Allegheny River above Pittsburgh; to have any assurance of the granting of permits for other river bridges in the County; and, to avoid the probability of a fine of $5000 per month against the County for each of the bridges not altered as ordered, it was necessary to let contracts at once for both the substructures and superstructures of the three down-town bridges.

Refusal of Permit for Bridge at Glassport. As further evidence of the sincerity of the War Department in this stand, it is well to note the following: October 24, 1919, the County submitted an application to the Secretary of War for a permit to build a bridge over the Monongahela River from Glassport borough to Wilson borough (now Clairton). No action was taken, and under date of April 7, 1924, a letter, in reply to our inquiry as to the status of the case, was received

from the office of the Secretary of War stating, "Action awaits satisfactory compliance by the County with notice to alter Sixth, Seventh, Ninth, Thirtieth and Forty-third Street bridges, which obstruct the navigation of the river."

This ultimatum introduced a very difficult problem. At the least calculation the program would carry through to late in 1928, and the uncertainties of the material market, and especially of the labor market, made contractors very reluctant to enter into agreements covering so long a period. As a partial offset to these unfavorable conditions, it was decided that work for the same type of construction for the three bridges should be let as a single contract, thus enabling the contractor to have a more or less continuous operation, rather than a long deferred contract, as would have been the case had the work on the Sixth Street bridge been let separately from the others.

Collaboration With Art Commission. Many studies of the proposed designs for these three bridges were made. The location of the south abutment of the Seventh Street bridge was shifted twice to meet different suggestions of planning bodies. Several distinct types of bridges were considered, and June 29, 1923, a design with simple truss spans, having the outlines of a continuous truss, was submitted to the city Art Commission, but it was deemed inadequate from an architectural standpoint. Early in 1924 a committee from the Art Commission was called into consultation and considered several general schemes for design; the demands for clearances and the limiting grades, ruling out any design of the deck structure type. This committee recommended that these three bridges should be identical in outline, and gave as its first choice a suspension design, and as second choice a cantilever design, with much greater preference for the former.

Self-Anchoring Suspension Type Approved. Past experience indicates that suspension bridge anchorages in this general location are subject to slipping, and the obstructions existing at all three bridges made it difficult, as well as undesirable, to carry the cables to a satisfactory land anchorage. The railroad tracks on the north side are between the shore pier and the abutment and further anticipated developments on the south side would interfere with the ordinary type of anchorage, and the problem was solved by selecting the self-anchoring type of suspension bridges. The three bridges will be similar in all

details; the length, from end to end of anchorages, being 860 feet each for the Sixth Street and Ninth Street bridges, and 884.8 feet for the Seventh Street bridge. The local conditions make necessary some minor differences in the approach spans of the three bridges. Heat-treated eye-bar chains were selected because of the reduced size and cost and the greater ease with which the anchorage details could be worked out. The stiffening girders, extending about three feet above the roadway, separate the roadway from the sidewalks, and are also designed as compression members to care for the horizontal pull on the eye-bar chains. Each bridge is designed with a roadway for two street-car tracks and two additional lines for vehicular traffic, with a maximum grade of 4.175 per cent., and two sidewalks each having a clear width of 10 feet. The details of the superstructure of the Seventh Street bridge are described in the *Engineering News-Record* of December 18, 1924.

The original bridge at Sixth Street was a wooden structure, of the Burr truss type built in 1818-1821, and followed in 1857-1860 by a wire suspension bridge, which was replaced by the present structure in 1890-1893.* This is by far the best of all the bridges which were freed by the County, and were it not necessary to rebuild to meet the interests of navigation it would serve the purpose for many years. Under our present program this bridge will be closed to traffic early in 1927.

The Seventh Street bridge, as it stood when the orders were issued, was a latticed, braced, inverted arch carrying two lines of traffic and two sidewalks. It was erected in 1884. Before the County was responsible for this bridge, trouble arose due to the slipping of the north anchorage; and toward the end of its use serious signs of failure developed in the eye-bar chains. A contract for the removal of the superstructure was awarded late in 1923, and the work was completed in the spring of 1924, after which the United States government removed the piers for their salvage value.

The original bridge at Ninth Street was of the wooden, Burr truss type and was erected in 1840. The present structure was erected on the old masonry, partly rebuilt, in 1890. The masonry is in poor condition and the superstructure too light and the roadway too narrow for present-day needs. The entire structure is under contract to be

*Proceedings, v. 11, p. 143.

torn down and removed, and the work is now under way. Those interested in the stories of earlier days should refer to the PROCEEDINGS of the Society for 1892,* and become familiar with an early exhibit of a flying-machine which took place from the roof of the original bridge.

Program for Completion. At the meeting with General Beach, March 12, the promise was made that these three down-town bridges would be ready to advertise in six months; and, on the afternoon of the last day, but one, of that period, the advertisement for the substructures appeared in the newspapers. The contract for the substructures was signed October 14, 1924, and that for the superstructures, December 31, 1924.

The schedule for the completion of the substructures of the bridges as it now stands is as follows:

Seventh Street bridge, ready for the steelwork, September 1, 1925; Ninth Street bridge, January 1, 1926; Sixth Street bridge, January 1, 1928.

For the superstructures, the dates are March 15, 1926, November 1, 1926, and November 1, 1928, respectively. This program meant the closing of the Ninth Street bridge at once. A study of the orders from the Secretary of War shows that it was always intended that the work on the Seventh Street and Ninth Street bridges was to be carried on simultaneously.

Thirtieth Street Bridge. The remaining bridge to be considered is at Thirtieth Street. Years ago Herrs Island was connected with the north bank by a bridge over the back channel, the responsibility for the maintenance of which is in dispute between the city of Pittsburgh and the Pennsylvania Railroad Company. Later, in 1887, a private company constructed a bridge across the main channel, connecting Thirtieth Street with Herrs Island. In 1902, when the stock-yards were moved from East Liberty to Herrs Island, the island end of the bridge was raised to give clearance over the railroad tracks and the connecting approaches erected on the island by the railroad company. Thus there are two or possibly three ownerships in the structure leading from the end of Thirtieth Street to Ohio Street. The two southerly spans over the main channel were destroyed by fire on July 8, 1921, and these were replaced by a foot suspension bridge,

*Proceedings, v. 8, p. 225.

which still stands. The location and clearance plans approved by the War Department are for a bridge starting at Penn Avenue and Thirty-first Street and extending to a point on Ohio Street. The details of this bridge are yet to be worked out and the distribution of cost between the various parties at interest has not been adjusted.

The Allegheny River bridge-raising controversy seems to be at an end, and within the next four years Pittsburgh will have six of the finest and most serviceable bridges to be found in any community.

DISCUSSION

Mr. Charles S. Davis, *Chairman*:* We are deeply indebted to Mr. Covell for the effort he has given to digging up the information in regard to the bridge-raising question and putting it in shape for permanent record. If there are any matters in relation to the points he has brought up on which any of you can furnish additional light, I am sure he would be glad to hear from you; or, if there are any points which you may wish to discuss, the opportunity is now given.

I see Mr. Schatz in the audience. We should be glad to hear from him.

Mr. F. C. Schatz:† I have enjoyed the paper very much, but I do not feel that I can add anything to what Mr. Covell has said. I am certainly glad the controversy is over. I am glad to know that the work is to be carried on as expeditiously as possible, and I am sure we will all be under obligation to the County Commissioners and the Department of Public Works for the splendid way in which they have gone at this whole problem, because I believe they have seen the right and have not swerved from it. I congratulate Mr. Covell on his very able and interesting paper.

Mr. A. R. Raymer:‡ The presentation of this paper which gives the complete history of the subject is very timely and also of great interest to all who are concerned in the development of the Allegheny River bridges. One can not help coming to the conclusion that the critics of the program of the County Commissioners in handling the construction of these bridges have not been properly informed, as the facts stated so clearly in this paper are a complete justification of the program now being followed by the Commissioners.

I shall not attempt to comment on the results reached in the design of the structures that will be built, as these matters have been carefully considered by the various commissions referred to in the paper and should be accepted as the best solution of the problem from all points of view.

*Consulting Engineer, Pittsburgh.

†Assistant Manager, Joseph Horne Co., Pittsburgh.

‡Chief Engineer, Pittsburgh & Lake Erie Railroad, Pittsburgh.

It was my pleasure a short time ago to listen to an address given by Secretary Hoover on engineering matters, in which he stated that in his opinion it would be desirable to have more men of engineering training engaged in public service.

I can not let this opportunity pass without expressing my appreciation of the organization that has been developed by the Commissioners of Allegheny County in forming the Department of Public Works, controlled by competent engineers, for handling the enormous expenditures involved in carrying out the unusual program of construction work. It has been my pleasure to meet officially the various members of this organization, and I am convinced that the executive and detail problems now before them are being handled as wisely and efficiently as such problems are handled by other large corporations. The organization of the Department of Public Works by the County of Allegheny is in harmony with the thought expressed by Secretary Hoover, and that organization should have the hearty support of the engineers of this Society.

It is only by having such a paper as this presented to the Society that the members can realize the magnitude of the problems and the efficient way in which they are being handled by Allegheny County.

I wish to congratulate Mr. Covell on the splendid presentation of this subject.

MR. J. W. ARRAS:* In the presentation of his paper on the Allegheny County bridge problem Mr. Covell has made an interesting and valuable contribution to this Society and to the community as well. Surely we can all rejoice in the fact that this long-drawn-out controversy is now happily at an end.

In contemplating the feature of this subject relating to the bridges over the Allegheny River at Pittsburgh it is important to regard the necessity of governmental foresightedness and the exercise of federal powers in dealing with otherwise undesirable questions. The radical modification of these Allegheny River bridges was not an accident. In 1880 the only low bridge over the Monongahela River between its mouth and Monongahela City was the bridge at Smithfield Street. When its reconstruction was undertaken, about 1883, there was no federal law regulating its clearance height and spans in the interest of

*Assistant Engineer, United States War Department, Pittsburgh.

navigation. The navigation interests, therefore, proceeded under the common law and succeeded by an order of the civil court in securing an increase in its clearance height from 36.3 feet to 49.5 feet. But, unfortunately, the Allegheny River a few years later had nine such low bridges at Pittsburgh with narrow and poorly placed channel spans. It was evident that, if ever the Allegheny was to be improved for navigation of equally deep draft as that on the Monongahela, the radical alteration of these bridges must naturally follow. The exceptional natural resources of the Allegheny valley in coal, limestone, fire-clay, building stone, glass sand, etc., were fully realized. Some day they would be needed. The Monongahela River coal would not hold out indefinitely.

In the early 'nineties the construction of the first dam on the Allegheny was receiving serious attention. About the same time the now existing bridge at Sixth Street was authorized. Looking forward to its future modification to meet the needs of navigation, the instrument of approval, dated May 2, 1891, carried a proviso, "That this approval shall not affect the right of the United States to order the clear headroom under the bridge to be increased whenever, in the opinion of the Secretary of War, such action shall be considered necessary or desirable." No further changes in the Allegheny River bridges occurred until the Pennsylvania Railroad Company, in 1900, applied for approval of a two-track bridge to be erected along the up-stream side of its lattice truss bridge across the river at Eleventh Street. Approval for this bridge was given by the Secretary of War under authority of the Act of March 3, 1899, under date of September 1, 1900. The instrument of approval in this case provided for the removal of one pier of the existing bridge so as to give a clear span of 320 feet; and further, "That whenever the work of raising the bridges now existing between this bridge and the mouth of the river is commenced the railroad company shall rebuild this bridge in accordance with the recommendations of the Board of Engineers which considered the plans." The recommendations referred to included a minimum height of 50 feet above the level of Davis Island pool and a width of channel span, when demanded, of 400 feet between the piers. The first step taken by the Pennsylvania Railroad Company under this permit was to remove the lattice truss bridge to temporary pile piers erected at the down-stream side. Following this, they pro-

ceeded to raze the old masonry and construct an entirely new bridge—the one now in use at that site—regardless of the permit issued for a different structure by the Secretary of War. Notwithstanding the remonstrances of the Engineer Department to this violation of the permit, the new bridge was constructed.

Here then were two bridges—massive structures intended to stand for many years—reconstructed at the old clearance heights, inadequate for the passage of the powerful pool towboats of the Monongahela River except at very low stages. The future modification of the last one was conditioned upon the modification of the other four below it, one of which had already been conditioned as to its modification upon the opinion of a Secretary of War as to when it might be considered necessary or desirable. It was evident that, if this method of dealing with the remaining Allegheny River bridges at Pittsburgh was to continue as they would from time to time require reconstruction, it would result eventually in nine modern, massive, costly structures, the future modification of each depending more or less on what happened to the rest of the bridges. As a governmental policy this was not in compliance with the intent of the Act of March 3, 1899, and, at best, was not promising for a sensible program. On the other hand, it was not fair to the owners to permit them to build costly, permanent structures at a low level and with poorly arranged channel spans, subject to early modification. It seemed better, therefore, to proceed under the Act of March 3, 1899, and, in the interests of future navigation, require the modification of all of the old bridges so that when new structures were erected the expense necessary to their compliance with the needs of navigation would be held to the minimum in every case.

Accordingly, the Allegheny River bridges at Pittsburgh were all reported to the Secretary of War as unreasonable obstructions to the navigation of the Allegheny River, and the initial hearing was held before Major Charles F. Powell, then District Engineer at Pittsburgh, in 1901. This hearing resulted in a mere statement of the two sides of the case, supported by a considerable amount of testimony. Major Powell, when relieved of the Pittsburgh station in the fall of 1901, submitted a hasty and rather brief report of the hearing upon which no action was taken by the Department. The subsequent hear-

ings, rulings of Secretaries of War, etc., have been fully covered by Mr. Covell.

Practically a quarter of a century has passed since this question was initiated. In the meantime two of the bridges have burned. One, the Baltimore & Ohio Railroad bridge at Herrs Island, was voluntarily rebuilt by its owner on plans approved by the Secretary of War. The Pennsylvania Railroad bridge has been raised. The old Forty-third Street bridge was barely able to stand until the splendid Washington Crossing structure was completed. The best that may be said for the Seventh Street and Ninth Street bridges is that they had served their day, being no longer adequate for present-day traffic requirements and displaying marked indications of decrepitude. This leaves the Sixth Street bridge alone as a comparatively modern structure capable of giving a good many years of service. Still, it is more than thirty years old and has long since repaid its cost. The city of Pittsburgh and the county of Allegheny, if they would hold their position in the industrial world cannot longer afford to ignore the importance of the Allegheny valley and its remarkable resources. Provision must be made for obtaining an outlet for the minerals and products of this valley if we are to hold our place and grow industrially. The actual cost to the County is the remaining life of the Sixth Street bridge. All things considered, this would appear to be a very small price to pay for the full and unobstructed navigable use of the splendid valley up the Allegheny.

MAJOR E. L. DALEY:* May I say a few words in the nature of an "amen" to what has been already so well said? A great deal of congratulation is fitting to-night—to Mr. Covell for his excellent paper; to the Society for this opportunity of listening to it; to Allegheny County and the city of Pittsburgh for having extracted the last penny's worth of value from these old bridges; to the river transportation interests on the Allegheny River, which are at the present moment enjoying better opportunities for navigation than they have had in forty years. I may say that since I came here, about twenty months ago, my relations with the county officials have been of the very best. I am sure that they have attempted to find the proper solution of this problem.

*Major, Corps of Engineers, U. S. Engineer Office, Pittsburgh.

As Mr. Covell has brought out, the War Department has always considered the removal of these three bridges that have been so prominently before the public of late, the Sixth Street, Seventh Street, and Ninth Street bridges, as two separate problems; first, the removal of the Seventh Street and Ninth Street bridges simultaneously—these two together having about the capacity of the Sixth Street bridge—and then the removal of the latter. With the removal of the Forty-third Street bridge, which has been the most obstructive bridge on the Allegheny River, navigation interests are now enjoying 6.5 feet more head room than they have had at any time during the past forty years. That is a big subject for congratulation. With the Ninth Street bridge actually in process of being razed and a contract let for a new Sixth Street bridge of proper clearances, I believe that navigation is about to come into its own.

The question of further constructions on the Allegheny River improvement has been placed by Congress in such form that not until the War Department is satisfied that the obstructing bridges are being removed can money be spent. I was satisfied from the work of the County Commissioners, when I made my report in July, that they were going to remove these obstructing bridges and I provisionally recommended the appropriation of $1,100,000 for work on the Allegheny River during this coming year. Unfortunately, although the Chief of Engineers incorporated this amount in his recommendations to Congress, the Budget Committee found it impossible to give the War Department $54,000,000, its estimated requirements, for the year. It appeared that the Allegheny River was to lose out. Since Congress decided that there was to be only about $40,000,000 available instead of the $54,000,000 needed by the Chief of Engineers, there has been such increased activity on the part of the County Commissioners that, during the past ten days, I have felt it incumbent on me to urge again upon the Chief of Engineers that some money be expended on the Allegheny River this year. I believe and I hope that, while we may not get the $1,100,000 that we think we could profitably spend during the coming year, the Chief of Engineers may be able to allocate some funds to show that the War Department is satisfied that the County Commissioners are about to remove the obstructive bridges, and carry out the orders of the Secretary of War. When we do get an allotment and when we do begin to spend money on

Locks 4 and 5, we can write *finis* to the chapter which has engaged the attention of the Pittsburgh river interests for the past twenty years.

MAJOR J. P. LEAF:* As a visitor from outside of Pittsburgh, I want to offer my congratulations to Allegheny County on the progress that has been made in freeing the Allegheny River bridge obstructions. It will be a great source of pleasure to see the Allegheny River finally improved. We on the outside could never understand why Pittsburgh, with its Chamber of Commerce and its boards for city and county improvement, has neglected the greatest asset and the greatest possibility for development they have; and they did not need to take it on theory, because the Monongahela River navigation has probably added more to the prosperity of Pittsburgh and Allegheny County than any other one element outside of the building of the Pennsylvania and other main-line railroads.

*Beaver County Commissioner and Consulting Engineer, Rochester, Pa.

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the William Penn Hotel, Tuesday, March 17, at 4:40 P. M., President W. B. Spellmire presiding, Messrs. Fohl, Goodspeed, Affelder, Dornbush, Rankin, Knowles and the Secretary being present.

The minutes of the last regular meeting, held February 17, were approved without reading.

Applications for membership from the following gentlemen, having been published to the Society pursuant to the action of the Board, were elected to membership:

MEMBERS

Acker, Albert J. — Scott, J. Walter
Miller, Lyman H. — Severn, A. B.
Undercoffler, William Carr

ASSOCIATE MEMBERS

Baer, Harry Louis — McKown, Harry Edwin

ASSOCIATE

Dickson, George Alexander

Applications for membership were received from the following gentlemen and their names ordered published to the Society. Assignment to the various grades of membership was made.

MEMBERS

Bryan, Joseph — Irons, Dean M.
Chaney, George Scott — Malady, John A.
Cott, Parker — Riddle, William M.
Drylie, William A. — Wales, Samuel Sigourney
Hamilton, William Bovard — Johnston, Harold L.

ASSOCIATE MEMBERS

Smith, Frank B. — Wilcox, William Ellis

ASSOCIATE

Horelick, Samuel

JUNIORS

Little, A. R. — Settle, Samuel Brittan

Applications for transfer were received from the following members and, after discussion, they were transferred to the grade of Member:

VanPelt, Arthur A. — Preston, Francis William
Hurtt, William Tisdale

Letter of resignation was received from Mr. Robert L. Martin and, after discussion, it was ordered accepted.

The report of the Secretary showing the financial condition of the Society at the close of business February 28, having been audited by the Finance Committee, was approved.

In the absence of Mr. Clifford, Chairman of the Entertainment Committee, the Secretary reported that a meeting had been held on March 3 to arrange for several inspection trips and social entertainments during the year 1925. The Committee had decided to lay out a definite program for these functions and had decided on four inspection trips to be held this Spring and four next Fall. They also decided to hold three Ladies' Night parties, one of which will be held March 27, notices to go out within the next few days. They also decided to hold a series of golf games, three in number, at the various country clubs in the Pittsburgh district. Mr. Charles Schley was appointed Chairman of a special committee to make the necessary arrangements.

The House Committee reported an evening attendance for the month of February of 391. The Committee also announced that arrangements have been made and notices mailed out for the Fifth Annual Chess Tournament, which will start Monday, March 23.

The meeting adjourned at 5:20 P. M.

K. F. Treschow, *Secretary.*

CIVIL SECTION

The regular bi-monthly meeting of the Civil Section was held in conjunction with the Local Section of the American Society of Civil Engineers on Tuesday, March 3, at 8:17 P. M., Chairman C. C. Dornbush presiding, 102 members and visitors being present.

The minutes of the last meeting, held January 13, were read and approved.

There being no further business, the paper of the evening was presented by Mr. V. R. Covell, County Engineer, Bureau of Bridges, Department of Public Works, Allegheny County, on "The Bridge-Raising Program on the Allegheny River."

Written discussion was presented by: A. R. Raymer, Chief Engr., Pittsburgh & Lake Erie R. R.; J. W. Arras, U. S. Asst. Engr., War Dept., U. S. Government.

The ensuing discussion was participated in by: Major E. L. Daley, Major U. S. Army, U. S. District Engineer; J. P. Leaf, City and Consulting Engineer, Rochester, Pa.; and the author.

On motion, the meeting adjourned at 9:23 P. M.

K. F. Treschow, *Secretary.*

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the William Penn Hotel, Tuesday, January 20, at 4:40 P. M., Vice President W. B. Spellmire presiding in the absence of the President, Messrs. Fohl, Khuen, Goodspeed, Weldin, Buell, Harrop, Leland and the Secretary being present.

The minutes of the last regular meeting, held December 9, were approved without reading.

Applications for membership from the following gentlemen, having been published to the Society, pursuant to the action of the Board, were elected to membership:

MEMBERS

Buchanan, E. R.
Daryman, Thomas A.

ASSOCIATE MEMBER

Brosky, Alphonse F.

ASSOCIATE

Clark, William F.

JUNIOR

McCreery, Maxwell

NATIONAL SOCIETY ACCEPTANCES

MEMBERS

Cadman, A. M.
Carr, U. U.
Foss, F. F.
Hook, C. Howard
Lavine, Saul
Matthews, Charles H.
Muller, H. N.
Robinson, J. French
Weise, Paul H.
Rodman, C. J.
Rust, W. F.
Smoot, C. H.
Sproull, C. W.
Willard, J. O.

ASSOCIATE MEMBERS

Cappeau, Jo P.
Demorest, George M.
Phelps, S. B.

ASSOCIATE

Elshoff, R. H.

JUNIORS

Cotter, George L.
Lindeman, Reginald G.
Mann, N. T.
Wood, Iver C.

Applications for membership from the following gentlemen were received and their names ordered published to the Society. Assignment to the various grades of membership is as follows:

MEMBERS

Beck, Wesley J.
Coles, Henry Taunton
Hill, Harry C.
Kline, Clement LeRoy
Lamberger, Louis Jacob
Laughner, Wm. Edward, Jr

ASSOCIATE MEMBERS

Beatty, Hollis Strong
Beatty, John David
Cross, Harry Walter
Duensing, Heinrich F. A.
Figee, Wm. Fred
Hoover, Calvin C.
Hurtt, Wm. Tisdale
Mason, Hugh B.
Moore, Emmett Hayden
Preston, Francis William
Pringle, Wm. Dick
Wolf, Frederick Nellis

JUNIORS

Bremmer, Floyd W.
Koelkebeck, Carl
Laverie, Marshall Alexander
LeCates, Raymond H.

NATIONAL SOCIETY ACCEPTANCES

MEMBERS

Benn, Charles L. (A.S.M.E.)
Craig, Allen B. (A.I.M.& M.E.)
Henderson, A. A. (A.S.C.E.)
Humphrey, Geo. S. (A.I.E.E.)
Strong, Carlton (A.S.C.E.)

ASSOCIATE MEMBERS

Bellows, Sidney R. (A.S.C.E.)
Goodwin, Irving D. (A.S.C.E.)

ASSOCIATES

Cone, James H. (A.I.E.E.)
Damrau, Edward A. (A.I.E.E.)
Grier, Louis N. (A.I.E.E.)
Herring, Thomas F. (A.I.E.E.)
Hill, Harold O. (A.I.E.E.)
Martin, F. L. (A.I.E.E.)
Svensson, Otto M. (A.I.E.E.)
VanPelt, Arthur A. (A.I.E.E.)

JUNIORS

Landis, Wm. C. (A.S.M.E.)
Manley, C. Reynolds (A.S.M.E.)
Peterson, J. M. (A.I.M.& M.E.)
Swift, Arthur D. (A.I.M.& M.E.)

Requests for reinstatement were received from the following gentlemen and, after discussion, the Secretary was requested to advise them of their reinstatement to membership:

Sprague, Norman S.
Wilkerson, T. J.

Request for transfer was received from Mr. Barton Stevenson and, after discussion, he was transferred to the grade of Member.

The Secretary reported the death of W. E. Winn, who joined the Society January, 1896, and died August 13, 1924.

The report of the Secretary showing the financial condition of the Society at the close of business December 31, having been audited by the Finance Committee, was approved.

Mr. Clifford, Chairman of the Entertainment Committee, reported that arrangements were complete for the Annual Banquet and that reservations received up to this time indicated that we were going to have one of the largest dinners in the history of the Society.

Mr. Fohl, Chairman of the Finance Committee, presented the following report:

"The budget of receipts estimated by the Committee the first of the year was $22,520, actual receipts were $25,125, making an excess of receipts of $2,605.

"The estimated budget for expenditures was set at $21,930, actual expenditures were $23,403, making an excess of $1,473. This excess is mainly due to expenses incident to our removal into larger quarters, together with the purchase of a motion picture machine and a new addressograph machine.

"All bills for the year 1924 were paid in full.

"We still have a deficit in our permanent fund of $2,845. This means that we have actually returned to this fund within the past two years $6,100. The Committee believes that the major portion of this deficit can be wiped out during the coming year.

"The Committee has been fortunate enough this year to secure enough advertising for our PROCEEDINGS to make a net profit of $1,315. This is the first time in the history of the Society that our publication has not cost us money, and it is the recommendation of this Committee that in the future a separate budget be made for the PROCEEDINGS in order that a special effort may be made each year to keep them at least self-supporting.

"It will be noted from the report of the Treasurer that there was only a balance of $1,100 in the general fund on December 31. We have assumed additional obligations in rent, which will mean that our 1925 budget of the expenditures will be larger. However, in view of the increased activities in the Society since the opening of the new clubroom and unusual number of new members coming in, the Committee feels that they were fully warranted in assuming this increase."

Mr. Leland, Chairman of the House Committee, reported an evening attendance of 452 for the month of December.

Owing, in part, to the addition to our quarters the attendance and membership has increased considerably. The attendance for the year 1924 was 3,856 in the evenings, an increase of 1,537 over 1923.

A meeting of the Membership Committee was held to assign applications received since the last meeting of the Board and act upon any resignations received.

The Secretary presented a letter from the Hon. William A. Magee, Mayor of Pittsburgh, asking that our Society appoint a representative to serve on a body of representative citizens to be appointed by the Mayor to study and make recommendations for the immediate relief of current traffic congestion in the downtown part of the city. After a general discussion it was moved and carried that Mr. W. A. Weldin be appointed to represent the Society on this committee and that the Secretary be instructed to write Mayor Magee thanking him for his invitation and notifying him of Mr. Weldin's appointment.

Mr. Spellmire called attention to the fact that we were to be deprived of hearing from our President at the annual meeting this evening, also that he was unable to preside at the last Board meeting due to illness. It was moved and carried unanimously that the members of this Board express their appreciation of the work done by Mr. Crabtree during his administration and that the Secretary be instructed to write him and also to send some flowers as a token of esteem from the Board of Direction.

The meeting adjourned at 5:30 P. M.

K. F. TRESCHOW, *Secretary.*

CIVIL SECTION—ANNUAL MEETING

The annual meeting of the Civil Section of the Engineers' Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Tuesday, January 13, at 8:10 P. M., Chairman E. V. Braden presiding, 53 members and visitors being present.

The minutes of the last annual meeting were read and approved.

The annual report of the Section was read by the Secretary.

The report of the Nominating Committee was read by Mr. C. N. Haggart, Chairman, as follows:

Officers and Members Civil Section,
Engineers' Society of Western Pennsylvania:

DEAR SIRS—Your Nominating Committee appointed to nominate officers for the Section for the year 1925 held a meeting and give below the following report:

C. C. Dornbush ....Chairman
V. R. Covell...Vice Chairman

C. S. Davis
Alex. Dann
R. P. Forsberg ....Directors
Richard Irvin
J. F. Laboon

Respectfully submitted.

C. N. HAGGART, Chairman,
N. H. ORR,
C. M. REPPERT,
Nominating Committee.

On motion, the nominations were closed and the Secretary instructed to cast a unanimous ballot in favor of the officers named, who were thereupon declared elected.

There being no further business, the meeting adjourned, and the regular bi-monthly meeting of the Section was called to order by Mr. Braden, in the absence of the new Chairman and Vice Chairman.

The minutes of the last bi-monthly meeting, held November 5, were read and approved.

The paper of the evening was presented by Mr. James S. Martin, Structural Engineer, Philadelphia Company, Pittsburgh, Pa., on "Safety and Construction Standards for Transmission Lines."

The ensuing discussion was participated in by: C. W. Kenney, Chief Const. Engr., West Penn Power Co.; M. E. Noyes, Sales Engr., Aluminum Co. of America; G. E. Flanagan, Mech. Engr., Heyl & Patterson, Inc.; C. N. Haggart, Structural Engr., Pittsburgh; S. N. Watt, Designing Engr., American Bridge Co.; R. R. Sutton, Asst. to Construction Engr., West Penn Power Co.; K. L. Kortlandt, Designing Engr., Carnegie Steel Co.; F. M. McCullough, Professor Civil Engineering, Carnegie Institute of Technology; and the author.

On motion, the meeting adjourned at 10:20 P. M.

K. F. TRESCHOW, *Secretary.*

ANNUAL MEETING

The forty-fifth annual meeting of the Engineers' Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Tuesday, January 20, at 8:10 P. M., Vice President Wm. E. Fohl presiding in the absence of the President, 106 members and visitors being present.

The minutes of the last annual meeting, held January 15, were read and approved.

The annual report of the Board of Direction, which included the reports of the Standing and Special Committees, the Sections and the Treasurer, was read as follows:

REPORT OF BOARD OF DIRECTION

The Board of Direction held ten regular meetings during the year, at which routine business of the Society was transacted.

During the year there were nine regular, the annual meeting and one special meeting of the Society. The total attendance was 2,594, the average being 259. The maximum attendance was 1,600, at the April 15 meeting, and the minimum 52, at the March 18 meeting. There was a general discussion after each of the above meetings.

At the close of the year the membership of the Society was as follows:

Honorary Members	1
Members	1,208
Associate Members	120
Associates	50
Juniors	84
Student Juniors	3
	1,466
Dropped	3
Resignations	47
Removed by death	16
	66
Accessions	231

Respectfully submitted,

K. F. Treschow, *Secretary.*

ENTERTAINMENT COMMITTEE

The Board of Direction,
Engineers' Society of Western Pennsylvania:

Dear Sirs—The following entertainments and inspection trips were held during the year:

April 5—Inspection trip. New Cecil plant, Allegheny County Steam Heating Company. Attendance, 78.

April 24—Ladies' Night Entertainment. Attendance, 92. Receipts, $138; expenditures, $262.08; deficit, $124.08.

May 3—Inspection trip. Hazel Atlas Glass Company, Washington, Pa. Attendance, 155. Receipts, $101; expenditures, $153.88; deficit, $52.88.

June 7—Inspection trip. Atlantic Exchange, Bell Telephone Company of America. Attendance, 105.

June 20—First Annual Golf Tournament. Shannopin Country Club. Receipts, $208; expenditures, $216; deficit, $8.

September 17, 18 and 19—Housewarming. Attendance, 400. Expenditures, $125.

October 18—Inspection trip. New Water-Softening Plant, South Pittsburgh Water Company, Carrick. Attendance, 125.

November 4—Election Night Party. Attendance, 350. Expenditures, $140.

November 13—Ladies' Night Party—Attendance, 83. Expenditures, $210; receipts, $124.50; deficit, $85.50.

Two theater parties were held in the Little Theater of the Carnegie Institute of Technology, through the courtesy of the faculty, the attendance on March 6 being 300, and at the April 4 party 200.

Respectfully submitted,

T. C. Clifford, *Chairman.*

HOUSE COMMITTEE

To the Board of Direction,
Engineers' Society of Western Pennsylvania:

The House Committee wish to report on work done during the year.

Owing to the increased attendance in the Society Rooms, it was found necessary to increase the size of the quarters by taking the Hawaiian Room, and a lease was signed with the William Penn Hotel effective September 1.

The attendance in the rooms for September to December has shown that the Society needed this additional space to continue its growth and usefulness.

The Chess Tourament was conducted by the Committee, the cup being won by Mr. L. C. Frohrieb.

The evening attendance for the year 1924 was 3,856, an increase of 1,537 over 1923.

Respectfully submitted,

E. D. Leland, *Chairman.*

FINANCE COMMITTEE

To the Board of Direction,
Engineers' Society of Western Pennsylvania:

Dear Sirs—Your Finance Committee wishes to report on financial condition of the Society at the close of business December 31, 1924, as follows:

The budget of receipts estimated by the Committee the first of the year was $22,520, actual receipts were $25,125, making an excess of receipts of $2,605.

The estimated budget for expenditures was set at $21,930, actual expenditures were $23,403, making an excess of $1,473. This excess is mainly due to expenses incident to our removal into larger quarters, together with the purchase of a motion picture machine and a new addressograph machine.

All bills for the year 1924 were paid in full.

We still have a deficit in our permanent fund of $2,845.00. This means that we have actually returned to this fund within the past two years $6,100. The Committee believes that the major portion of this deficit can be wiped out during the coming year.

The Committee has been fortunate enough this year to secure enough advertising for our Proceedings to make a net profit of $1,315. This is the first time in the history of the Society that our publication has not cost us

money, and it is the recommendation of this Committee that in the future a separate budget be made for the PROCEEDINGS in order that a special effort be made each year to keep them at least self-supporting.

It will be noted from the report of the Treasurer that there was only a balance of $1,100 in the general fund on December 31. We have assumed additional obligations in rent, which will mean that our 1925 budget of the expenditures will be larger. However, in view of the increased activities in the Society since the opening of the new clubroom and the unusual number of new members coming in, the Committee feels that they were fully warranted in assuming this increase.

Respectfully submitted,

WM. E. FOHL, *Chairman.*

PUBLICATION COMMITTEE

To the Board of Direction,
Engineers' Society of Western Pennsylvania:

During the year three meetings of the Committee were held, with an average attendance of five.

Papers presented at the general Society meetings	11
Section meetings	15

Two meetings of the Practising Engineers' Section were held during the year for discussion of the business of the Section.

Twelve of the papers presented have been published in the PROCEEDINGS, or will be published later.

The publication of the PROCEEDINGS is now up to date.

Respectfully submitted,

G. M. GOODSPEED, *Chairman.*

MEMBERSHIP COMMITTEE

To the Board of Direction,
Engineers' Society of Western Pennsylvania:

The Membership Committee held ten meetings during the year 1924 to transact the usual business of the Committee.

Sixty-one engraved invitations were sent out to the executives in the Pittsburgh district, resulting in 18 new members.

Seventeen hundred letters of invitation were also sent to members of the four National Societies—American Society of Mechanical Engineers, American Society of Civil Engineers, American Institute of Electrical Engineers, and the American Institute of Mining and Metallurgical Engineers. Eighty-five acceptances have been received to January 20, 1925. Forty-seven of these were elected prior to December 31, 1924.

Upon the suggestion of one of our members, Mr. D. W. Allan, the Committee recommended to the Board that a quartet be formed of four new members of the Society, who would offer their services for all entertainments given by the Society free of charge, the Society to remit their dues for such services. The quartet to be known as "Engineers' Society of Western Pennsylvania Quartet," and this name to be used whenever their services were required at entertainments other than those of the Society. This recommendation was approved by the Board of Direction.

The activity of the Membership Committee for 1924 is shown by the following list of new members. Corresponding figures are also given for the years 1923 and 1922:

	1924	1923	1922
Honorary Members	0	0	0
Members	132	54	62
Associate Members	37	28	14
Associates	23	5	6
Juniors	26	10	14
Student Juniors	3	1	0
Reinstatements	10	1	8
Total new members for year	231	99	104
Dropped	3	63	37
Resignations	47	53	49
Deaths	16	9	8
	66	125	94
Net change in number of members	+165	—26	+10

The membership of the Society as of December 31, 1924, also 1923 and 1922, is as follows:

	1924	1923	1922
Honorary Members	1	1	1
Members	1,208	1,091	1,129
Associate Members	120	100	92
Associates	50	34	32
Juniors	84	72	80
Student Juniors	3	3	1
	1,466	1,301	1,335

In addition to the personal solicitation of new members, the use of engraved invitations to executives, and the letter of solicitation to the four National Societies, the work of the Membership Committee included the careful reviewing of applications, as well as the proper grading of these applicants into the various classes of membership; also the passing on reinstatements and resignations.

I wish to thank the members of the Committee, and the Secretary of the Society, for the time and effort devoted to this work. The Society is under obligation to the following members of this Committee for their hearty co-operation: Messrs. Paul Caldwell, J. L. deVou, J. S. Fulton, W. H. Jarvis, T. H. McGraw, Jr., G. W. Quentin, E. Rahm, Jr., T. H. Ross, W. B. Skinkle and G. E. Stoltz.

Respectfully submitted,

WALTER B. SPELLMIRE, *Chairman.*

TREASURER'S REPORT

To the Board of Direction,
Engineers' Society of Western Pennsylvania:

DEAR SIRS—Your Treasurer desired leave to submit the following report for the year 1924:

RECEIPTS

Dues Collected	$16,771.55
Entrance Fees	1,175.00
Sales of Advertising Space	4,030.80
Sale of Magazine PROCEEDINGS	787.21
Sale of Society Pins	129.00
Interest on Bonds	690.00
Interest on Bank Balances	353.27
Income on Banquet	6,594.00
Sale of Inspection Trip Tickets	599.00
Ladies' Night Entertainments	262.50
Golf Tournament	208.30
Rental of Motion Picture Machine	35.00
Miscellaneous	83.66
Total Normal Receipts	$31,719.29

DISBURSEMENTS

Administration and General	$16,364.78
Cost of Magazine PROCEEDINGS	4,684.49
Furniture and Fixtures	1,082.73
Housewarming Expenses	106.88
Election Night Party	151.88
Inspection Trips	840.48
Golf Tournaments	242.45
Ladies' Night Entertainment	438.11
Other Entertainments	117.59
Annual Banquet 1924	5,955.56
Annual Banquet 1925	154.23
Total Normal Disbursements	$30,139.18

CASH ASSETS

	Dec. 31, 1923	Dec. 31, 1924
Permanent Fund (Bonds)	$13,303.75	$13,615.00
Cash (Fidelity T. & T. Co.)	1,904.71	4,164.71
Reserve Fund:		
Cash (Fidelity T. & T. Co.)	2,500.00	2,500.00
General Fund:		
Cash (First National Bank)	648.71	953.82
Total	$18,357.17	$21,233.53
Increase in Assets	2,876.36	
	$21,233.53	

BONDS OWNED—PERMANENT FUND

1—$1,000 Butler Water Company 30-year 5% Bond, maturing September 2, 1931—No. 9	$ 930.00
2—$1,000 Connellsville Water Company 5%, Nos. 317-318, maturing October 1, 1939	1,700.00

2—$1,000 Portsmouth, Berkley & Suffolk Water Company 5%, Nos. 465-66, maturing November 1, 1894	1,860.00
2—$1,000 Jamison Coal & Coke Company 5%, Nos. 1502-1503, maturing May 1, 1931	2,000.00
2—$1,000 Union Steel Company 5%, Nos. 38642-38643, maturing December 1, 1952	2,130.00
2—$1,000 Pennsylvania Railroad Company 4½%, Nos. 27320-27321, maturing August 1, 1960	1,965.00
3—$1,000 Jones & Laughlin Steel Corporation 5%, Nos. 3020-3021-3030, maturing May 1, 1939	3,030.00
	$13,615.00

Attention might be called to the fact that our bonds have increased in market value to the extent of $311.25.

Our finances in general are in better shape at the end of this year than they have been for the past five years. We had no unpaid bills on hand December 31 and increased our bank balance over last year about $300. Increase in assets, $2,876.36.

Respectfully submitted,

A. Stucki, *Treasurer.*

BUILDING CODE COMMITTEE

To the Board of Direction,
Engineers' Society of Western Pennsylvania:

I am pleased to be able to report that the Building Code Committee of the City of Pittsburgh has substantially completed its work. To do this has required nine years, during which 472 meetings of the Committee have been held.

Yours very truly,

George H. Danforth,
Representative of Committee of the Engineers' Society of Western Pennsylvania.

REPORT OF CIVIL SECTION

To the Board of Direction,
Engineers' Society of Western Pennsylvania:

Dear Sirs—I wish to submit the report of the work done by the Civil Section during the year 1924.

Four regular meetings of the Section were held during the year. The average attendance was 78; the maximum being at the January 8th meeting with an attendance of 148, and the minimum 49 at the May 6th meeting.

January 8—Annual meeting. "Sand and Gravel for Concrete in the Pittsburgh District," by C. M. Reppert, Brown & Reppert, Inc.

March 4—"Engineering and Safety Problems of the Coal-Mining Industry of Great Britain," by R. V. Wheeler, D. Sc., and Director of Mines Department, Experimental Station, Sekmeals, Sheffield, England; and Henry Walker, C. B. E., and Deputy Chief Inspector of Mines of Great Britain, London, England.

May 6—"The Erection of Steel Bridges," by N. H. Orr, Assistant Engineer, American Bridge Company, Pittsburgh, Pa.

November 5—"Some Notes on Foundations," by Charles N. Gow, Consulting Engineer, Boston, Mass.

Respectfully submitted,

E. V. Braden, *Chairman.*

REPORT OF MECHANICAL SECTION

To the Board of Direction,
Engineers' Society of Western Pennsylvania:

DEAR SIRS—I submit herewith report of the work done by the Mechanical Section during the year 1924 as follows:

Four regular meetings of the Section were held during the year. The average attendance at these meetings was 69, the maximum being 86 at the June 3rd meeting, and the minimum 52 at the December 2nd meeting.

An average of four participated in the discussion. The papers presented were:

February 5—Annual meeting. "A New Thought in Fuel Engineering," by Henry O. Loebell, Vice President and General Manager, Combustion Utilities Corporation, New York City, N. Y.

June 3—"Classification of Pyrometers and Their Application," by R. W. Newcomb, General Manager, Charles Engelhard, Inc., New York, N. Y.

October 6—"Recent Developments in High Pressure and Superheat," by B. N. Broido, Chief Engineer, Superheater Company, New York, N. Y.

December 2—"Industrial Heating," by Thornton Lewis, Vice President, Heating & Ventilating Corporation, Philadelphia, Pa.

Respectfully submitted,

W. C. BUELL, JR., *Chairman.*

REPORT OF MINING SECTION

To the Board of Direction,
Engineers' Society of Western Pennsylvania:

DEAR SIRS—I submit herewith report of work done by the Mining Section during the year 1924 as follows:

Three regular meetings of the Section were held during the year. The average attendance at these meetings was 44, the maximum being 66 at the February 25th meeting, and the minimum 20 at the June 24th meeting.

An average of nine participated in the discussion. The papers presented were:

February 26—Annual meeting. "The Engineer and the Housing Problems," by L. A. Brandt, Project Engineer, Commerce Housing Corporation, Pittsburgh, Pa.

June 24—"Concentration in Coal Mining," by E. B. Moore, Manager, Pittsburgh Office Coal Service Corporation, Pittsburgh, Pa.

November 25—"Rock Dusting Bituminous Coal Mines," by T. G. Fear, General Manager, Inland Collieries Company, Indianola, Pa.

Respectfully submitted,

F. A. McDONALD, *Chairman.*

REPORT OF PRACTISING ENGINEERS' SECTION

To the Board of Direction,
Engineers' Society of Western Pennsylvania:

DEAR SIRS—I wish to submit herewith report of the Practising Engineers' Section of the work done during the year 1924 as follows:

Two meetings of the Section were held during the year. The attendance at the two meetings was 33, 21 attending the February 13th meeting and 12 the May 21st meeting. At the May 21st meeting a talk was given on "Credits and Collections," by L. B. Blum, Blum-Weldin Company, Pittsburgh, Pa.

Regular business of the Section was discussed at the annual meeting and officers were elected for the year.

Respectfully submitted,
H. S. HARROP, *Chairman.*

REPORT OF STEEL WORKS SECTION

To the Board of Direction,
Engineers' Society of Western Pennsylvania:

DEAR SIRS—I wish to report on work done by the Section during the year 1924 as follows:

Four meetings of the Section were held during the year. The average attendance at these meetings was 69, the maximum being the October 28th meeting with an attendance of 76, and the minimum 54 at the March 25th meeting.

An average of eight participated in the discussion. The papers presented were:

January 29—Annual meeting. "Manufacture and Use of Seamless Tubing," by W. B. Chencellor, Department Superintendent, Ellwood Works, National Tube Company.

March 25—"Refractories for Metallurgical Furnaces," by G. A. Bole, Superintendent, Ceramic Experiment Station, United States Bureau of Mines, Columbus, Ohio.

October 28—"Pickling of Sheet Steel," by Ewart S. Taylerson, Engineer of Tests, American Sheet & Tin Plate Company, Pittsburgh, Pa.

December 18—"How to Obtain High Thermal Results in the Boiler Room and Relation Between Efficiency and Economic Values," by J. G. Worker, Assistant to President, American Engineering Company, Philadelphia, Pa.

Respectfully submitted,
G. D. BRADSHAW, *Chairman.*

REPORT OF TELLERS

To the Members, Engineers' Society of Western Pennsylvania:

Dear Sirs—The undersigned tellers publicly canvassed the ballots in the annual election of officers of the Society at noon, Tuesday, January 20, 1925, and wish to report the following:

Ballots received	479
Irregular ballots	3
Ballots Counted	476

For President	Walter B. Spellmire	474
For Vice President	George T. Ladd	472
For Treasurer	A. Stucki	472
For Directors	W. L. Affelder	474
	T. C. Clifford	467

Respectfully submitted,

W. C. Buell, Jr., Chairman,
George B. Page,
W. F. Sanville,
Tellers.

The Vice President thereupon declared the following gentlemen elected:

For President	Walter B. Spellmire
For Vice President	George T. Ladd
For Directors	W. L. Affelder
	T. C. Clifford

Vice President Fohl appointed Past Presidents Danforth and Stucki to escort the President-elect to the chair, and addressed the meeting as follows:

"It is deeply to be regretted that, owing to illness, our President is not able to be with us and take part in this ceremony. I know, however, that he is well satisfied that the affairs of the Society are being placed in sure and trustworthy hands for the ensuing year. I know also that I speak for the entire membership when I assure Mr. Spellmire that we will give him our hearty support in his efforts to make this a memorable year in the history of the Society.

"Mr. Spellmire, I take pleasure in presenting you this gavel, which is the outward sign of your authority. Gentlemen, you may greet your new President."

Mr. Spellmire addressed the meeting as follows:

"I thank you, Mr. Chairman, and members of the Engineers' Society of Western Pennsylvania. I assure you that I will do my part to carry out what our Chairman has suggested as far as I may be able to do it. It is regrettable that, owing to illness, Mr. Crabtree is unable to be with us tonight. On the occasion of the annual meeting of our Society it is customary for the retiring President to make an address. Owing to his illness, however, he realized some time ago that he would not be able to be with us tonight, and it was possible to arrange for a very interesting paper this evening in place of the annual address of the President, which we will have at a later date.

"Before making further reference to the paper, I wish to remind the members of the Society that provision was made many years ago whereby all papers presented during the year are carefully scrutinized and marked for the merit they contain. And when a paper is found of sufficient value a medal is awarded. The papers of the year 1923 have been examined by the 1924 committee and a joint paper was found worthy of a silver medal. The subject of the winning paper was 'Pulverized Fuel for Large Boilers,' by Mr. L. W. Heller and Mr. J. C. Hobbs."

No further business coming before the Society, Mr. Spellmire introduced the speaker as follows:

"The paper for this evening is 'A Panoramic View by High-Power Metallography of the Transformations in 1.00% Carbon Steel, Martensite to Pearlite.' I have no doubt all this means a lot more to you gentlemen than it does to me. I do not find any of these words in the electric dictionary with which I am familiar. However, not to be taken off my guard, I found on looking it up in Webster that the word 'Martensite' was derived from the name of Professor Martens, the German metallurgist.

"The paper is to be presented by a friend of the past President of this Society, Mr. Sergius P. Grace, of New York, formerly of this city. Like all of our past Presidents, he still maintains an interest in the Society, and it is through him that we are able to bring to you this evening Mr. Francis F. Lucas, of the Research Laboratories of the Bell Telephone Company and the Western Electric Company, whom I now have the pleasure of presenting to you."

The ensuing discussion was participated in by: P. H. Brace, Research Dept., Westinghouse Elec. & Mfg. Co.; S. L. Wilcoxson, Asst. Test Engineer, Carnegie Steel Co.; E. H. Dix. Metallurgist, Research Bureau, Aluminum Co. of America; W. J. Merten, Metallurgical Engr., Westinghouse Elec. & Mfg. Co.; F. N. Speller, Metallurgical Engr., National Tube Co.; Walter B. Spellmire, Mgr., General Electric Co.; Dr. John A. Matthews, V. P., Crucible Steel Co. of America; T. D. Lynch, Mgr., M. & P. Dept., Westinghouse Elec. & Mfg. Co.; and the author.

On motion, duly seconded and carried, a vote of thanks was extended to Mr. Lucas for his very interesting paper.

On motion, the meeting adjourned at 10 P. M.

K. F. TRESCHOW, *Secretary.*

STEEL WORKS SECTION

The annual meeting of the Steel Works Section of the Engineers' Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Tuesday, January 27, at 8:18 P. M., Chairman G. D. Bradshaw presiding. 81 members and visitors being present.

The minutes of the last annual meeting, held January 29, were read and approved.

The annual report of the Section was read by the Secretary.

The report of the Nominating Committee was read by the Secretary as follows:

Members and Officers, Steel Works Section:

Dear Sirs—Your Nominating Committee met today in the Society rooms at noon to nominate officers for the Steel Works Section for the ensuing year, and the following members were nominated:

L. C. Edgar	Chairman
A. C. Fieldner	Vice Chairman
T. J. McLaughlin D. D. Pendleton B. R. Shover J. J. Shuman E. W. Trexler	Directors

Respectfully submitted,

R. W. Andrews, Chairman,
J. A. Morton,
Nominating Committee.

On motion, the nominations were closed and the Secretary instructed to cast a unanimous ballot for the officers named, who were thereupon declared elected.

No further business coming before the Section, it was adjourned and the regular monthly meeting called to order by Mr. W. C. Buell, in the absence of the new Chairman and Vice Chairman.

The address of the retiring Chairman was presented by Mr. Grant D. Bradshaw, Andrews-Bradshaw Company, Pittsburgh, Pa., on "Concentration in Boilers."

Written discussion was presented by: C. J. Rodman, Research Engr., Westinghouse Elec. & Mfg. Co.; K. VonEltz, Mgr., Reisert Automatic Water Purifying Co., New York, N. Y.

The ensuing discussion was participated in by: G. W. Smith, Supervising Chemical Engr., The Hagan Corporation; T. H. McGraw, Jr., Dist. Sales Mgr., Erie City Iron Works; M. F. Newman, Mgr., Water Purifying Dept., Wm. B. Scaife & Sons Co.; H. A. Jackson, Chemical Engr., The Hagan Corporation; B. A. Ludgate, Asst. Engr., Pittsburgh & Lake Erie R. R.; F. N. Speller, Metallurgical Engr., National Tube Co.; R. W. Andrews, Andrews-Bradshaw Co.; L. F. Kuhman, Sales Engr., Andrews-Bradshaw Co.; R. E. Hall, Physical Chemist, U. S. Bureau of Mines; and the author.

On motion, duly seconded and carried, a vote of thanks was extended to Mr. Bradshaw for his very excellent paper.

On motion, the meeting adjourned at 10:35 P. M.

K. F. Treschow, *Secretary.*

CONCENTRATION IN BOILERS*

By Grant D. Bradshaw†

The importance of a knowledge of the effect and amount of concentration in boilers is much more important under modern operating conditions than it was twenty years ago. At that time boilers were small and were operated at low rating. Very little attention was paid to the treatment of boiler feed—first, because the importance of such treatment was not fully realized from an efficiency standpoint; second, because the cost of coal was much less; and third, because, as time goes on, the natural sources of feed-water supply have become more and more contaminated.

Under present conditions, with boilers of larger and larger size being installed, with less and less water capacity per horse-power developed, and with higher and higher rating, the necessity of taking concentration into account is more and more evident.

In addition to this, as we progress higher and higher in the scale of efficiency of boiler and plant operation, troubles which were formerly taken for granted or considered as insurmountable, are now being taken into consideration, and the remedy sought. The advent of superheaters and a record of the total temperature of superheated steam which most modern plants now keep with recording thermometers shows up at once the throwing of water by a boiler. This formerly in many cases passed unnoticed. It now presents in a visual way evidence of what is going on in a steam line; whereas before, troubles due to foaming and priming, unless they were of an extent to do serious damage, were not evident except in excessive troubles due to wear and improper lubrication, which in years past were usually blamed on the cylinder oil.

Of recent years, more and more attention has been focused upon the relation of degree of concentration to the tendency of boilers to foam, but progress along these lines has been of comparatively recent development, and a comparison of results from different plants shows wide variations. In some plants, boilers can not be operated without becoming wild when the concentration is over 150 grains or sometimes as low as 100 grains per gallon. In other cases the concentration can

*Presented January 27, 1925. Received for publication March 26, 1925.
†Andrews-Bradshaw Co., Pittsburgh.

be run up to 1000 to 1500 grains per gallon, or even higher, without causing a boiler to become uneasy. One of the most satisfactory studies of this relationship has been given by C. W. Foulk, of Ohio State University, published in *Industrial and Engineering Chemistry**. Another exhaustive article is one by R. E. Hall of Pittsburgh in *Mechanical Engineering*†.

The amount of concentration which will cause foaming depends not only upon the amount of salt contained in the water, but also upon the softness of the water and upon the concentration of the small amount of oil, vegetable matter, etc.

In testing the water for softness, for instance, in one case a single drop of soap solution when shaken in the sample may produce a great deal of foam. If the water is harder, however, it may take ten or a dozen drops to produce this same amount of foam. In this case the soap solution represents the concentrated soap-making materials in the concentrated boiler water. If we could determine the concentration of the actual foam-making elements as separate from the tests of concentration usually taken, and consider these results in their relation to what is usually termed boiler concentration, it might be possible to correlate many varying results which now appear contradictory. Again, the design of the boiler is to some extent responsible, in that it is the design and circulation of the boiler which produces agitation. This again, can be comparable to the soap test referred to. Even in a soft water, simply the dropping in of a drop of soap solution will not cause a foam, until the bottle is violently shaken. In the same way in a boiler, if the circulation is continuous and of uniform velocity, and does not produce violent agitation in local spots, the amount of foam will be much less than in a boiler where there is violent local agitation, other conditions being equal.

According to Mr. Foulk, the point at which foaming will occur —in other words, the degree of concentration necessary to cause foam —is dependent upon the relation of the minute solids to the soluble salts in the boiler water. In my opinion, however, of even more importance is the concentration of the actual materials which increase the surface-tension to a point at which bubbles become more or less permanent. Each set of conditions gives different points above which concentration should not be carried. This point in any given case is,

*v. 16, p. 1121.
†v. 46, p. 810.

in general, fairly well defined although it is usually preceded more or less by a gradual increase in the amount of moisture carried out of the boiler drum with the steam to the steam line. Accordingly in each particular steam plant, with its own particular source of feed-water supply and treatment, the degree of concentration at which trouble is to be expected can be fairly well determined.

Of course, it is impossible to prevent concentration as long as soluble impurities are carried into the boiler with the feed water. As the water is there evaporated, the impurities will concentrate in the boiler, and the extent of this concentration will be determined by the relative amount of moisture which is carried out of the boiler as moisture. In fact, Mr. F. R. Low, former president of the American Society of Mechanical Engineers, puts it very clearly in an editorial in *Power*,* entitled "Blowing Down a Boiler through the Steam Nozzle." He says, "According to the first principles of arithmetic the impurities removed from a boiler over a long period must equal those brought in by the feed water."

Assume, for example, a properly treated water which does not deposit scale in the boiler. If this feed-water contains 15 grains of impurities per gallon, these 15 grains must come out of the boiler, with the amount of actual water taken out of the boiler *as water*. If this amount is two per cent. of the feed, the concentration will build up to a point where this two per cent. will carry away in a given length of time the total amount of impurities carried into the boiler in that same length of time. In this particular case, two per cent. represents one-fiftieth of the total amount of feed. Therefore, this one-fiftieth must be of a concentration 50 times the concentration of the feed-water—in this particular case 750 grains, or 12,750 parts per million. In other words, the concentration will vary directly with the quality of the feed-water and inversely with the percentage of water blown out of the boilers. Whether this be blown out through the steam nozzle or through the blow-off valve is immaterial.

In the interests of efficiency this blow down should be kept as small as possible. In other words, the concentration should be allowed to build up to the maximum point at which the boiler can be operated without becoming "wild," whether this point be 150 grains per gallon, or 2000 grains per gallon.

*v. 61, p. 27.

Mr. Hall in his paper in *Mechanical Engineering* recommends, from a scale-forming standpoint with his particular treatment, that the concentration be kept below 2000 parts per million, which is only 118 grains per gallon. This may be correct from a treatment standpoint, but the boiler operator must balance the slight increase in scale which might be formed according to Mr. Hall's theory, against the actual material loss occasioned by the excessive blow down necessary with Pittsburgh waters. For instance, a 20-grain or even 30-grain water is not uncommon in this district. To keep the concentration down to 117 grains per gallon with a 30-grain water would require blowing down of roughly 25 per cent., or a loss of heat from this practice of roughly six per cent. If, however, this particular plant could be operated with a concentration of 600 grains instead of 117 the blow down would be five per cent. instead of 25 per cent., and the heat loss only 1.2 per cent.—a direct saving of 4.8 per cent. in efficiency, and such a saving will pay for a lot of labor for boiler cleaning.

These figures are really very conservative because I have assumed that the concentration of the water blown off through the blow-down connection is of as great concentration as the average in the boilers. Actually, it is usually much less, being diluted with fresh boiler feed due to the method by which the feed is introduced into the boiler circulation. The heat lost from this source in many cases is in practice much greater than the figures I have given. This will be again referred to later.

By blow-off, of course I mean all water blown out of the boiler whether into the steam line with the steam or into the sewer through the boiler blow-off connection.

We can better visualize conditions by examining Fig. 1.

To see what this means in terms of frequency and amount of blow downs, take, for instance, this cross-drum boiler with drum 54 inches in diameter, about 15 feet long. A blow down of four inches would amount to roughly 170 gallons. If the output of the boiler is 1000 boiler horse-power, and the quality of the feed-water is 15 grains per gallon, we are introducing into the boiler 54,000 grains of impurities per hour. If, for instance, the point at which this boiler starts to foam violently is at 300 grains per gallons, it will be necessary in the interest of safety to blow this down when the concentration reaches a point of, say, 250 grains. Each blow down will, therefore, take out

of the boiler 250 × 170 or 42,500 grains total, which means that in this particular case the boiler would have to be blown down four inches every 45 minutes in order to keep the concentration from rising above 250 grains if no moisture passed out with the steam.

With 1.5 per cent. going out with the steam, this would take out 54 gallons of water per hour at a concentration of 250 grains per gallon, or 13,500 grains per hour, leaving 40,500 to be removed through the blow-off valve, or a blow down about once each hour. In a case like this, if the water tender should forget himself and let the boiler run, say for two hours without blowing down, long before this time the critical point would have been passed and the boiler

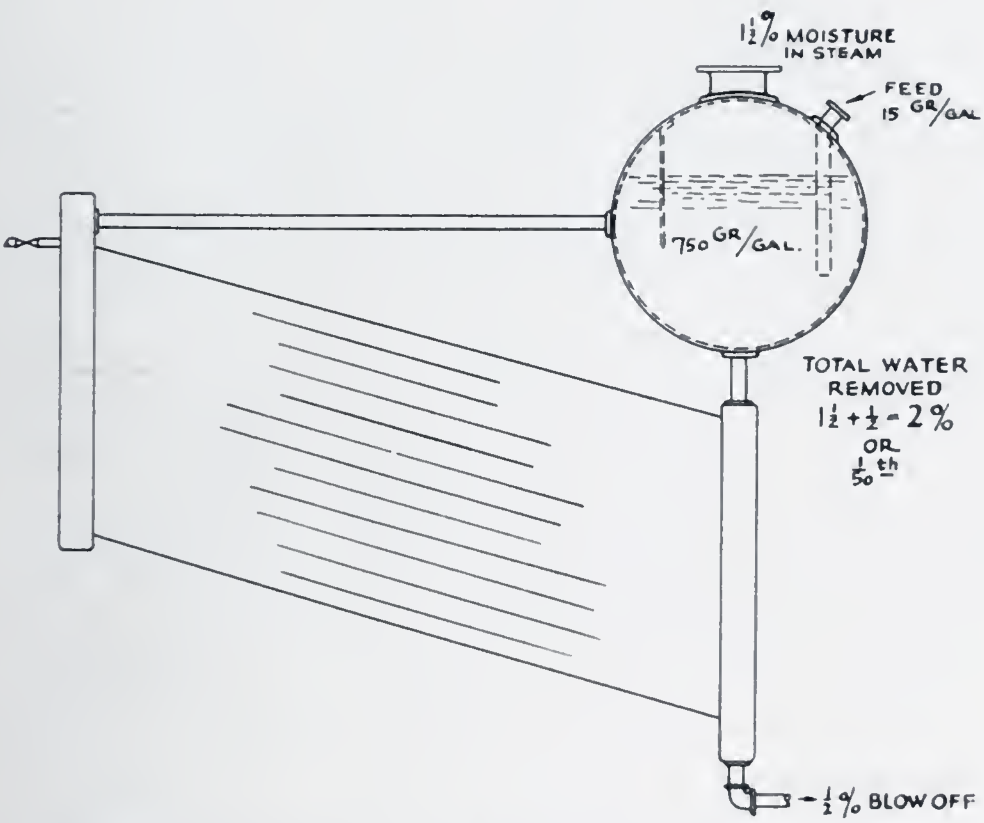

Fig. 1. Relation of Blow-Off and Moisture in Steam to Concentration.

would be throwing water violently into the steam lines. It is conditions such as these that have been responsible for a great many of the wrecked cylinder heads that we all run across at different times in our experience. If we had to keep the concentration below 117 grains per gallon with 1.5 per cent. moisture, the steam line would take 6350 grains per hour. Each blow down would take 20,000 grains and the boiler must be blown down about every 25 minutes.

An illustration can be cited. At one of the big industrial plants they report the foaming point at between 11,000 and 12,000 parts per million. They try, however, to keep the maximum concentration

below 8000 parts per million (465 grains per gallon) by having one man whose duty it is to manipulate surface blow-offs. Even with this extreme care at times the concentration gets past the danger mark and the boiler foams over into the steam line to relieve itself.

Using 15-grain feed-water is equivalent to putting into a boiler over 5500 pounds, or nearly three tons of impurities every month for every 1000 horse-power developed, and it takes a pretty high concentration to get rid of this without losing a lot of water and heat.

Feed-water treatment is nowadays of course considered long past the point of discussion, as to whether or not it is an economy where one has a feed-water containing impurities, which means in 99 out of 100 cases. Treating the feed-water, however, in order to get rid of the 15 grains, is pursuing a will-o'-the-wisp. This is readily evident from a consideration of the chemistry of feed-water treatment.. We will take, for example, the simplest case—that is calcium sulphate, which by the way is the important scale-forming impurity in our water in the Pittsburgh district and Western Pennsylvania in general.

Reaction: $Ca\,SO_4 + Na_2\,CO_3 = Ca\,CO_3 + Na_2\,SO_4$
Atomic weights: $136 + 106 = 100 + 142$

You can see from the above, the most common reaction in the treatment of feed-water by soda-ash. If there is free acid present, this is neutralized by lime which in turn again forms calcium sulphate, which is then treated with soda-ash to form calcium carbonate and sodium sulphate. The calcium carbonate is a precipitate, finely divided to be sure, but can be settled and filtered out, at least to a great extent. The sodium sulphate, however, is as soluble as ordinary table salt, and no commercial method of eliminating this from the water is at present known. If the feed-water is filtered after the reaction, and settling has taken place, the greater part of the calcium carbonate can be removed, but this still leaves the sodium sulphate, and for every 100 grains of calcium sulphate which have been removed there are left behind 104 grains of sodium sulphate. If the feed-water is not filtered, but is treated—for instance in the feed-water heaters, or even by the injection of a solution of soda-ash into the feed-water line—it will carry not only the sodium sulphate, but the calcium carbonate as well, and the removal of 100 grains of the hard scale-forming calcium sulphate will be accomplished by substituting 178 grains of other impurities.

If treated with caustic soda we still have the same amount of sodium sulphate formed and, as far as concentration is concerned, have not bettered matters. The same remarks apply to treatment with sodium phosphate.

$$2\ Na_3\ (PO_4) + 3\ Ca\ SO_4 = 3\ Na_2\ SO_4 + Ca_3\ (PO_4)_2$$

An actual example of a typical untreated water of the Pittsburgh district, and the same water treated in a lime-soda-ash system is given as follows:

	Raw	Treated
Volatile and organic	1.15	0.65
Silica	0.45	0.45
Calcium carbonate	2.43	0.88
Calcium sulphate	11.32	....
Magnesium sulphate	4.86	....
Magnesium hydroxid	....	0.48
Sodium carbonate	....	2.48
Sodium sulphate	0.53	18.46
Sodium chlorid	9.40	10.22
Sodium hydroxid	....	0.94
Total grains per gallon	30.14	34.86

From this it can be seen that treating with lime and soda-ash not only does not reduce the impurities in the feed-water, but actually increases them, and to this extent increases the concentration in the boilers. However, the impurities that are left in are practically non-scale-forming materials and the efficiency of the boiler as a heat absorber is not interfered with. The treatment has done what it was designed to do—prevent scale—but actually the boiler concentrations using treated water will ordinarily be greater than with raw water.

The treatment with "zeolite" produces similar results, to the extent that the calcium and magnesium salts are removed and their corresponding sodium salts left in their place, with the same effect; that is, the total impurities in the feed-water are increased rather than diminished, even though the water itself has what is called "zero hardness."

There are several ways of determining the concentration in a boiler. The first two are based on obtaining from the boilers a sample

of sufficient amount. This sample is then either analyzed chemically in the laboratory or is evaporated and the residue weighed. A third method is to mount on the boilers a resistance unit, taking a continuous sample from the boiler's circulating system, measuring its resistance to the conduction of electricity, and recording the amount of current on a delicate ammeter graduated in an arbitrary scale.

Another method of determining concentration in boiler water (and one which can be done in two minutes' time in the plant) is the measurement of the amount of sodium sulphate present by precipitating the total sulphates in a 10-cc. sample with barium chlorid and finding the amount of dilution with distilled water necessary in order

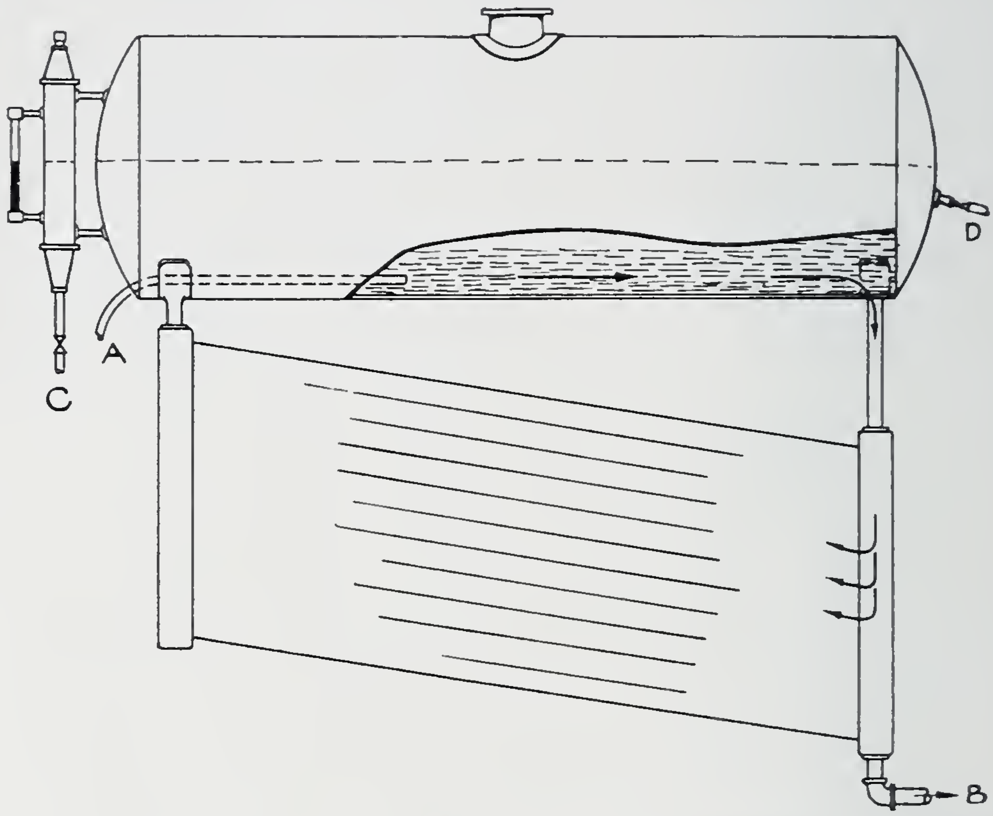

Fig. 2. Circulation of Feed-Water in Longitudinal-Drum Boiler.

that a narrow intensely illuminated slot is just visible through a given thickness of liquid.

To obtain even approximately accurate results by the first two methods it is necessary to obtain an accurate sample. This is not the easy matter it may seem. This is illustrated graphically in Fig. 2-4.

In a boiler of the type shown in Fig. 2, the feed-water is introduced at *A*, and in this, as in the other cases, it is necessary to take the sample at a point where this feed-water will have been thoroughly mixed with the highly concentrated water of the boiler, and this is not as easy a matter as appears on the surface. The feed-water, due

to being colder, does not immediately mix with the water in the drum, but flows backwards along the bottom of the drum down the rear circulating tubes, past the blow-off and into the lower rows of boiler tubes. If a sample is taken from the blow-off (*B*) without shutting the feed-water valves for an appreciable time before the sample is taken, part of the blow-off water will contain fresh feed-water, and the sample will not be a true sample. If it is taken from

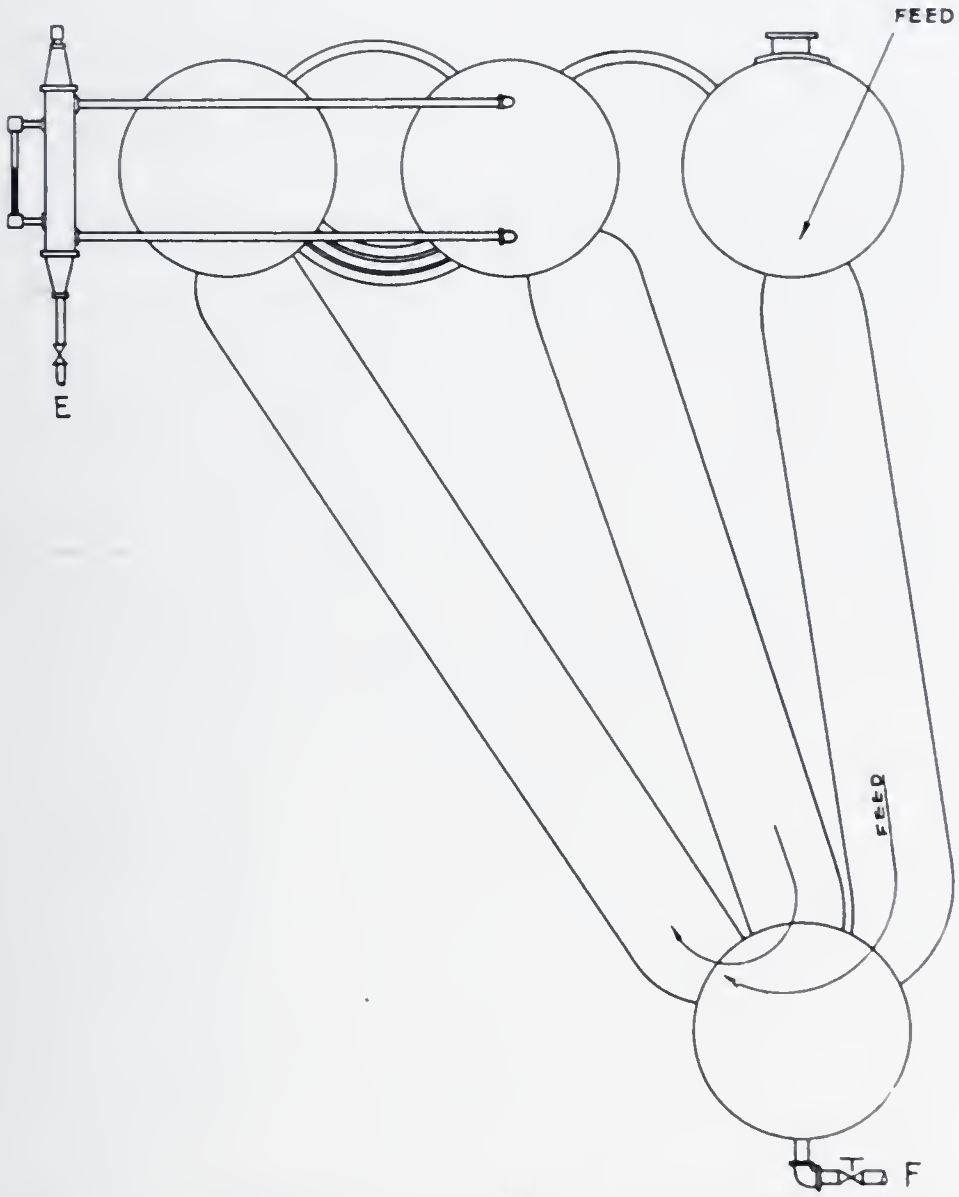

Fig. 3. Circulation of Feed-Water in Bent-Tube Boiler.

blowing down the water-column connection (*C*), the same thing holds true, although not to quite as great an extent, but a very marked difference will usually be found between that sample and a sample taken from point *D*, which is taken entirely from the direct current of the fresh feed-water. Of course, it is the latter sample that represents the true concentration of the boiler water.

Fig. 3 shows the feed-water in this type of boiler. Here again it passes directly by the blow-off connection. In this boiler, however, it

would be perfectly practicable to obtain a sample from the gage-column connection, provided this is blown out sufficiently to remove entirely the condensed steam with which it is filled.

Fig. 4 shows the usual cross-drum type. Here again the same condition is encountered; only in this case the sample from the gage-column connection will not prove to be a reliable indication of the boiler concentration, and about the only place to take a true sample would be at some such point as that marked *H*.

These sketches show why the usual samples taken from the boiler blow down sometimes give such widely varying results; for this, in nine cases out of ten, is the point at which the usual samples for concentration analysis are taken.

In the type of boiler shown in Fig. 2 there is also a great chance for variation of the concentration in the various drums, due probably

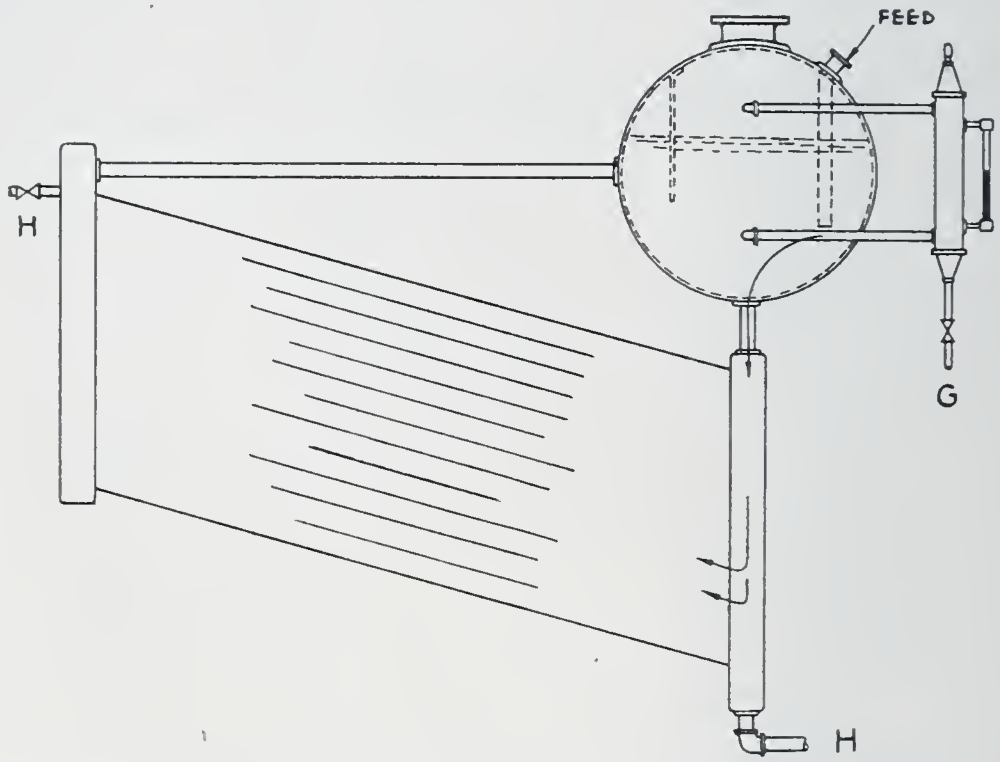

Fig. 4. Circulation of Feed-Water in Cross-Drum Boiler.

to a lack of equalization of the feed supplied to each. In one particular case the average concentration on two drums of a four-drum boiler was only 1020 parts per million (60 grains per gallon), while that in the other one was more than twice that, actually 2150 parts per million, or 120 grains per gallon. In this case the samples were taken just below the water-level near the front of the drums, and the figures above are the average of four days' reading taken twice a day in four different boilers in the same house.

In using the resistance apparatus, to determine concentration, it

must be remembered that the results are only comparative, and that the readings will change with the change in the relative proportion of the various elements in the feed-water. This instrument has its place, however, and where the feed-water analysis does not change too rapidly, it can be used as a fair guide, although, even at best, this method has its objections.

I noticed at a plant in Kansas City a novel use of this apparatus, which was used for keeping track of the concentration of the condensate from the turbo-generators. These turbines exhausted into surface condensers, and the condensate was returned to the boiler house. The circulating water, however, was Missouri River water, which has a high amount of impurities, largely in suspension. At this plant they were troubled by periodic splitting of condenser tubes, which, if not caught in time, introduced a relatively large proportion of Missouri River water directly into the feed-water. The matter was so serious that they used an indicating resistance machine for determining the concentration by conductivity, and they had a man stationed watching this machine night and day. When a tube split, and leakage developed, it would immediately register on the machine and the turbine was shut down. They told me that if this was not caught within 15 minutes the boilers would be so wild that the whole plant would have to be shut down.

In checking the accuracy of concentration, it is advisable to balance up the totals. In other words, make up for the boilers a "dirt balance" in the same way that heat balance is made up to prove the accuracy of a boiler test. In other words, after the boiler has been on the line long enough to reach the average concentration, which depends upon the amount of moisture leaving with the steam, and the amount of blow downs, the total amount of dirt going into the boiler should equal that going out with the steam plus that going out with the blow-off. The analysis of the feed-water can be comparatively easily determined, as can also an analysis of the blow-off. Then a sample of the steam should be collected, condensed and analyzed. When this is done, if the tests have been accurately taken, the total quantity of gallons of feed-water per day, times the grains per gallon, should equal the total number of gallons of steam, times the grains per gallon, plus the total number of gallons blown down, times the number of grains per gallon in the blow-off. As Mr. Low said, this is simply a matter

of arithmetic, and if it does not balance up, then the amount that it is out represents the degree of inaccuracy in the test.

For example, assume that the test has shown there are 15 grains per gallon in the feed-water; that the concentration of the boiler is 250 grains per gallon; that there are two blow downs, of 170 gallons each per day (0.4 per cent.); and the amount going out with the steam is four per cent. If the output of the boiler is 1000 boiler horse-power, this means roughly 3600 gallons per hour, or 86,500 gallons per day. The total input of the impurities into the boiler for a day therefore is 1,295,000 grains. Blown down twice a day, 170 gallons at 250 grains equals 42,500 $\times$ 2, or 85,000 grains per day in blow-off, equivalent to 340 $\div$ 86,500 $=$ 0.4 per cent.

There must be 1,295,000 — 85,000, or 1,210,000, in the steam, or 14 grains per gallon. If the recording calorimeter shows two per cent. moisture average over 24 hours, the concentration of this moisture and, therefore, the concentration of the water in the top portion of the boiler must be 14 $\times$ 50, or 700.

If the calorimeter should show four per cent., the concentration would be 350.

Feed-water $=$ Blow-off $+$ Steam

$86{,}500 \times 15 = (340 \times 250) + 4\% \times (86{,}500 - 340) \times 350$

$1{,}295{,}000 = 85{,}000 + 1{,}305{,}000$

Input 186 pounds $=$ 12.1 pounds blow-off $+$ 172.1 pounds in steam

This would be considered a pretty good check, the main discrepancy being the analysis of 250 grains per gallon in the blow-off and the 350 grains per gallon shown in the moisture in the steam. This might be dilution of the blow-off with fresh feed-water, as previously pointed out, or may be inaccuracy in the calorimeter, which would be very possible due to the large amount of moisture present, which approaches the limit of the throttling calorimeter.

This "dirt balance" method does, however, give a fair check upon the accuracy of the figures and should always be employed wherever possible to show up grave errors in the same manner that a modern boiler test always ends up with a heat balance.

Not only does boiler design have its effect upon the point of concentration at which foaming will take place under given conditions, because of local agitation, but also, by determining to some extent the amount of moisture which is carried out with the steam, boiler design will determine the maximum concentration which will ordinarily be

carried with the usual schedule of blowing down, which is mostly done once a turn.

In other words, it is not usual for the blow down to exceed 0.5 per cent. If the boiler were designed so that no moisture whatever were delivered with the steam it would mean that only 1/200 of the total amount of moisture entering the boiler would leave by the blow-off, provided blow down took out average concentration. In other words, the concentration would rise to 200 times that of the feed-water. If the feed-water were 15 grains per gallon, the concentration would rise to 3000 grains per gallon. This would ordinarily be well past the point at which a boiler would be too wild to be operated. Actually, however, this is a condition rarely even approximated and actually impossible without means for mechanically preventing the water from reaching the steam lines. The conditions in the usual boiler are that the moisture leaving with the steam varies from one-half up to 1.5 or 2 per cent., or even higher. In the best condition, say, 0.5 per cent. moisture in the steam and 0.5 per cent. blow down, this equals a total of one per cent., or the concentration in this particular boiler with 15 grains feed-water would reach 1500 grains, of which half would go into the steam line and half out the blow-off. If this were changed to 1.5 per cent. moisture in the steam and 0.5 per cent. out the blow-off, or a total of two per cent., the concentration in the boiler would reach 750 grains. If it were necessary to prevent priming to keep the concentration down to 300 grains—in other words, blowing down at a point of about 250 grains—it would be necessary to blow down a total of 4.5 per cent., which plus the 1.5 per cent. going out the steam line would equal a total of six per cent.

The fact that a boiler is provided in a design with superheating elements would of course have no effect upon this analysis, any more than applying a superheater to the boiler externally, because the dry superheated steam would be carrying in suspension the impurities which ordinarily would be carried out with the water, and the concentration would not be affected. In such boilers, calorimeters can not be used and the method of checking up the "dirt balance" must depend upon condensing the steam and then determining the dirt content. This can easily be done, but care must be taken to place the sampling nozzle in such a location, and proportion the velocity through it in

such a way, that a true average sample is obtained in the same manner as in sampling dust in blast-furnace gas.

A word here may not be out of place regarding throttling calorimeters, calling particular attention to the necessity of determining the "normal" of each instrument as provided in the A.S.M.E. Power Test Code of the American Society of Mechanical Engineers. To show the necessity of this I have here a series of tests made with exceptional care and laboratory precision on four different types of throttling calorimeters, each type tested with various sizes of orifices. These orifices varied from ⅜ inch down to 1/16 inch in diameter. Some of the calorimeters were lagged with asbestos, some steam jacketed, and some treated by both methods. The normal of these various types of sizes—in other words, the number of degrees which must be added to the lower reading to correct for the proportional effect of radiation, velocity impact, etc.—varied all the way from 1.6 up to 76 degrees F. In running a test in the field the normal should be determined both before and after the test; or, if only one normal test is taken, it should be directly after the test, for a piece of pipe scale lodging in the orifice might easily change the normal anywhere from 5 to 12 degrees.

In summing up the situation with respect to the boiler concentration, the outstanding fact is that a balance is always established between the impurities entering the boiler with the feed-water, and the sum of the impurities leaving with the blow-off and leaving in the steam. It is the last two items which determine the degree of boiler concentration. In order to reduce heat losses as much as possible the blow down should be kept low. Needless to say, the impurities leaving with the steam must by all means be scrubbed out and kept from passing through the steam system, as they not only act as an abrasive, but also clog up steam-using apparatus, and cut the lubricating properties of cylinder oil.

Lastly, when concentrations have been measured, a check upon them should be obtained by working up a "dirt balance."

DISCUSSION

MR. W. C. BUELL, JR., *Chairman*:* Mr. Bradshaw's study has been of very great interest to us and undoubtedly there are a number of points that will occur to you on which you want enlightenment, or with which you possibly are not in agreement. The subject is open for discussion. Mr. Jackson, will you start the discussion?

MR. H. A. JACKSON:† I wish to congratulate Mr. Bradshaw on this paper. I am glad that he has brought out so forcibly the great concentration that occurs in boilers fed with impure but treated water.

As too great concentration can not be tolerated, we must face the fact that adequate blow down must be given a boiler. The greater the amount of soluble salts in the feed the greater the blow down required to keep the boiler water within proper limits. The blow down needed on some waters may be inconveniently large, but there is no help for it. If it is abnormally large, then a heat exchanger or a small but continuous blow down would be a proper investment. On waters within the Pittsburgh district the blow down will vary from 0.5 to 32 per cent. of the feed as calculated from actual analyses that I have seen. Boiler plants fed with water needing a blow down of only 0.5 per cent. of the feed in order to take care of the solubles should adopt some means other than blow down to prevent accumulation of suspended solids in the boiler, so that the actual blow down may be kept to the minimum really required.

On the other hand, where the water is so high in sulphates as to require a 32 per cent. blow down, proper treatment of the water can not be given unless such a large blow down is resorted to, and the expense of this is too great unless a heat exchanger be provided. It is all a matter of definite calculation based on a proper analysis of the feed-water.

In regard to the difference in concentration in boiler-water samples taken at various points in the boiler, I can not see such a disturbing influence of the feed as is brought out in this paper. I understand it is claimed that only about one per cent. of the water is evaporated in a single passage through a tube, in which case the volume of boiler

*Mechanical Engineer, Pittsburgh.
†Chemical Engineer, Hagan Corporation, Pittsburgh.

water circulating is one hundred times that of the entering feed, so that the influence of the dilute feed would be lost a short distance beyond its point of entrance.

I know there are a lot of mistakes made in the sampling of boiler water. Considering the care and time required to make an analysis of boiler water, some care should be exercised in the collection of the samples.

Mr. Grant D. Bradshaw: The ratio of feed-water to circulation in the boilers as given by you at one per cent. would appear to be rather low. If it were only one per cent., the variation in the samples from different parts of a boiler should not be as large as tests seem to indicate. The example which I gave in the paper was an actual example, and would indicate that it is necessary that a sample for determining boiler concentration should be properly taken if erroneous results are to be avoided.

Mr. R. E. Hall:* I have been very much pleased to hear the paper this evening, as it places before us in concrete figures the factors which are of significance in determining the concentration of solubles and insolubles in a boiler water. Also, it indicates forcibly the amount of material which may be carried into the steam lines by a small percentage of moisture in the steam. It was recognition of this fact which led me inevitably to the conclusion, published some months ago† that the starting point for boiler-water conditioning was the steam nozzle. With removal of the danger of the steam carrying entrained boiler water with it, strenuous methods may be applied to prevent the growth of adherent scale on the evaporating surfaces.

The speaker has referred to an article by me in *Mechanical Engineering*, November 1924. May I make the correction that this article, in mentioning a concentration of 2000 parts per million of sulphate refers to sulphate radical, SO_4, and not to sodium sulphate, Na_2SO_4. In terms of the latter, the total concentration would be 2960 parts per million. If to this are added the chlorids, carbonates, hydroxids, etc., the total concentration of solubles will approximate 4000 parts per million.

It would be ideal to operate on concentrations such as this, for

*Physical Chemist, Pittsburgh Experiment Station, U. S. Bureau of Mines.
†Iron and Steel Engineer, June 1924, v. 1, p. 321.

the maintenance of the proper carbonate-sulphate ratio in boilers operating at 150 $\pm$ 25 pounds gage pressure would be quite simple. On Pittsburgh waters, however, when the percentage of make-up is high, it is almost necessary to carry a higher sulphate concentration, with the result that difficulty arises in maintaining the correct carbonate-sulphate ratio, owing to the ready decomposition of sodium carbonate into caustic soda at boiler-water temperatures. When the carbonate-sulphate ratio is only partly maintained, there results a soft scale, which is a mixture of calcium carbonate, calcium sulphate, and magnesium silicate and hydroxid. Its removal is very easy.

In regard to Mr. Foulk's article, I consider it one of the outstanding contributions to our knowledge regarding foaming. Two points from this article may be emphasized: (1) the foam-producing tendency of insoluble suspended matter varies inversely with the size of the individual particles; (2) if the concentration of suspended insoluble material is less than 500 parts per million there is little tendency toward foaming, regardless of the concentration of soluble material. It is an advantage, therefore, from (1), to precipitate the solid phase in boiler water as crystalline calcium carbonate, and avoid as far as possible any flocculent very finely divided precipitates. As regards (2), there is no excuse at all for the presence of 500 parts per million of suspended insoluble matter in boiler waters.

Mr. B. A. Ludgate:* Has the author had any experience in the use of barium compounds for water treatment, and is the higher cost of treatment by barium (which is about five times that for the soda-lime treatment) fully justified?

Mr. Grant D. Bradshaw: All I can say is that, so far, I have run across only one plant in the Pittsburgh district that was using barium, and I believe this particular plant is now using lime and soda-ash. I understand that the cost is pretty high, and they figured they could lower it considerably by using lime and soda-ash. Just what the actual cost of the barium is I do not know. It is probably considerably more than the lime and soda-ash.

Mr. F. N. Speller:† To what extent have means been used to recover the heat in the blow-down water? I understand that heat

*Assistant Engineer, Pittsburgh & Lake Erie Railroad, Pittsburgh.
†Metallurgical Engineer, National Tube Co., Pittsburgh.

exchangers have been used abroad to some extent for this purpose. Mr. Bradshaw's figures indicate that the concentration in the boiler is maintained more by the removal of water with the steam than through the blow-off. Would it not pay to reduce the amount carried through with the steam and increase the blow down, using a heat exchanger as a matter of economy? More attention is now being paid to pure steam, especially in steam-heating plants.

MR. R. W. ANDREWS:* I have traveled around the country quite a little and have run across just one plant where they are attempting to recover blow-down heat loss. They have not as yet put it in service. They have it piped and are starting to put it in service; but that is the only plant of which I have heard.

My impression as to why there is little attempt to recover the heat from the blow-off is simply because that is one of the things that has been absolutely neglected. In other words, the blow-off is looked upon as simply a necessary evil, and consequently it is up to the water tender or fireman to blow down. That is all there is to it. It is a feature of engineering that has not been gone into as other things have. That is my personal feeling.

MR. L. F. KUHMAN:† A question has arisen as to why barium treatment of water is not more commonly used. In addition to the remarks that have already been made, relative to this treatment, there seems to be in addition to the high cost of barium other factors which sometimes enter into its probable use. It might be interesting to note that in one plant in the Pittsburgh terrritory, where barium treatment was tried for a period of about four months, considerable trouble was experienced with oil in the feed-water. This oil came from the condensate of reciprocating engines, and also was in the raw feed-water. The oil could not be eliminated. When this water was treated with the usual lime and soda-ash treatment it saponified and, of course, caused something of a foaming action in the boilers. When the barium treatment was used the oil did not saponify, but adhered to the tubes and other parts of the boiler, causing blisters, which in turn necessitated frequent tube renewals.

*Andrews-Bradshaw Co., Pittsburgh.
†Sales Engineer, Andrews-Bradshaw Co., Pittsburgh.

A very accurate account was kept of the cost of operating the boilers before, during and after the barium treatment, and it was found that, due to the high cost of the barium plus the trouble experienced as the results of the oil in the water, the costs were, I believe, some fourteen times the cost of the lime and soda-ash treatment (I do not remember the exact figures). In this particular plant, barium was discontinued for that reason.

Mr. T. H. McGraw, Jr.:* I think we have all come this evening to learn as much as we can about securing better conditions in the operation of boilers. I know I appreciate what Mr. Bradshaw has so clearly brought out—that we get an increased concentration as the different methods of treating feed-water are applied. But can we not bring out in discussion some more instructive corrective methods? We realize that the various water treatments all produce concentration and we must keep down our concentration. Now, with the amount of talent we have here, we should be able to find out what is the best method of getting away from this concentration. I know that certain people represented here to-night understand how to do that pretty well—certain filtration systems, I believe, made integral with the boiler feed-water plant, and there are remarkable claims made for a reduced consideration; and I do not know but that the author of this paper has a pretty good device for taking care of some of that concentration that goes out through the steam nozzle. I want to learn something. I came in all the way from the country to get some points and I would like to hear a real discussion as to how to get this concentration down either by filtration processes or by taking out some of these impurities at the mouth of the boiler.

Mr. G. W. Smith:† We are fully in agreement with nearly everything Mr. Bradshaw has said to-night. We think he has done us all a very valuable service by thus recounting some of his experiences.

As a matter of fact there is only one way of reducing "the concentration of boiler water," and that is by removing the materials which concentrate. Everything that goes in a boiler must, for continued operation, eventually come out, whether in blow down, in steam, by filtration, or even by turbining. The latter is one of the

*District Sales Manager, Erie City Iron Works, Pittsburgh.
†Supervising Chemical Engineer, Hagan Corporation, Pittsburgh.

most popular, even if one of the least desirable of the various methods of maintaining low concentrations of dissolved and suspended materials in a boiler water—that is, by allowing a large portion of the dissolved material in a feed-water to precipitate on the heating surfaces.

When a feed-water is so treated as to prevent scale deposition there usually result equivalent quantities of materials which remain in solution, and of materials which will be precipitated as sludge. Removal of these may be accomplished either partially by filtration of the unconcentrated treated feed-water, or more satisfactorily in many cases, by filtration of the boiler water.

The materials which will remain in solution may be removed either by blow down or by moisture in steam, both of which may incidentally remove a portion of the suspended material. In practice we have found it desirable to reduce blow down to a point just sufficient to keep the concentration of solubles within proper limits, and to use the more economical filtration to remove sludge and suspended solids.

The best illustration of the above statements is the reaction between calcium sulphate and sodium carbonate to form calcium carbonate and sodium sulphate. A solution of calcium sulphate evaporated in a boiler will not concentrate beyond its boiler temperature solubility. When this is exceeded, the calcium sulphate is removed from solution by scale formation. Properly controlled treatment with soda-ash will produce sodium sulphate and non-adherent calcium carbonate, which will accumulate in the boiler water until removed as rapidly as they enter.

In the case of many very hard feed-waters the most desirable concentration of solubles from the standpoint of treatment or dry steam production may require a rather large blow down. In such cases a steam purifier will permit higher concentrations to be maintained and yet protect the steam-using units—that is, treat fully for scale prevention, make reasonable blow downs, keep the suspended solids as low as practicable, and expect some wet steam to be produced; but remove the moisture from the steam as it passes from the boiler.

The "dirt balance" which Mr. Bradshaw describes may be useful in another way than that which he has mentioned. A serious dis-

crepancy in the "dirt balance," after the boiler has been on the line a few days, where the solids going in exceed those coming out, is almost *prima facie* evidence of scale or sludge accumulation. In fact, I understand that in the very careful work done by Dr. Hall at the United States Bureau of Mines he has been able to calculate the amount of scale deposited during a boiler campaign, and the composition of the scale.

Scale deposition can also be detected by comparing the ratio between sulphate radical in the boiler water and sulphate radical in the feed-water, with the same ratio for chlorin. Chlorid ion forms no insoluble compounds with the materials present in boiler water and can be removed, consequently, only in solution. The chlorin ratio therefore indicates the true number of concentrations reached in the boiler, and, if the sulphate ratio is lower, calcium sulphate must have been deposited.

The sulphate concentration is usually, however, a much better measure of boiler concentration than the chlorin concentration, as sodium sulphate is usually by far the predominant salt in solution in the boiler water.

Mr. M. F. Newman:* Mr. Bradshaw has stated an axiom. When there is put into a boiler water containing a known total of impurities of all kinds, the ultimate of such impurities collecting in the boiler is in direct ratio to the amount of evaporation. However, when it comes to the actual operation of boilers, there are so many varying factors that the noticeable effects of concentration do not necessarily correspond with the expected logical conclusions. It does not always follow that proportionately as great an amount of solids leaves the boiler in the steam as goes in with the water. Since soluble substances are necessarily present, the water in steam will take out some of these substances, but the precipitated matter takes on various forms, and apparently at times reaches a very high concentration without an appreciable quantity of it being in the steam. The amount of impurities thrown out by the steam as theoretically calculated would cause much more difficulty than has generally been experienced.

There are a lot of things that are not known about the reactions taking place within a boiler. An isolated case or an isolated reaction

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does not solve the problem. In the past, as one gentleman has well brought out, it was more a matter of getting steam and not multiplying the instruments to check up the condition of the water and steam. Owners of power-plants were not willing to spend money for the supervision required to trace out the factors in each individual plant for the improvement in boiler operation that all of us hope eventually to see accomplished, particularly with reference to allowable concentrations.

Wet steam arises from causes other than concentration alone. It can not in all cases be attributed to the water and it can not be attributed to the boilers alone. Our experience, covering a wide field for quite a number of years, has shown that in many cases wet steam is caused by more than one factor, and as a rule it is quite difficult to get all of the related facts from the observations of the average boiler-room force.

There are peculiar things related to circulation. The speaker brought out some of them. There are also some peculiar things connected with the relation between substances in solution that remain soluble and those that are precipitated. A very puzzling factor is that connected with boiler feed-water passing through an open heater receiving steam from reciprocating machinery. Theoretically, the oil and grease introduced with the exhaust would in most cases result in foaming after a certain number of hours of boiler operation; but, as a matter of fact, this does not occur in practice. About eighteen years ago chemists in one of the United States government departments showed by formula that where the soluble impurities in boiler feed-water were 30 grains per gallon, such water could not be used for boilers without foaming; nevertheless, there have been a number of instances where feed-water has been successfully used with as much as 100 grains per gallon and concentrations reached a maximum of 4000 grains per gallon in return-tubular boilers without foaming. The limit for concentration to control the impurities carried out with steam really becomes a function of the work that a particular type of boiler is doing when fed with a particular feed-water supply. When the water contains appreciable quantities of solids in solution, or solids in solution and suspension, the effects in the boiler will vary with the load conditions and the type of boiler. The ideal condition, of course, is distilled water. That seems to be a very simple procedure, but

distilled water gives rise to a number of disturbing factors connected with corrosion.

The control of concentration does not necessarily reside in an empirical formula based on the grains per gallon of soluble salts in the boiler feed-water. The effect of heat and concentration upon many forms of soluble organic substances in feed-water is very difficult to ascertain, and without knowing the exact composition of such substances their ultimate effect with relation to concentration can not be successfully predicated. The problem is further complicated by the use of sodas directly applied to the feed-water as it is delivered to heaters or boilers. Mr. Bradshaw, however, has made perfectly clear that there are well defined factors with which to work in determining the total of impurities entering a boiler in a given time under specific operating conditions.

The best control of concentration, as well as the best protection from scale and corrosion, is obtainable when the feed-water is standardized to a minimum hardness and alkalinity so that this definite information about it can be used to determine blow-down intervals to limit the concentration for particular operating conditions, as well as the time for taking a boiler out of service to empty.

Mr. C. J. Rodman:* Mr. Bradshaw has presented a most interesting and valuable contribution to the knowledge of boiler-water concentration. Because of foaming, priming, wet steam, frequent blow down, excessive corrosion and erosion of equipment, Mr. Bradshaw has shown that the loss of boiler efficiency has been largely due to conditions surrounding excessive boiler concentration. Enlightenment along these lines indicates a wanton waste of fuel due to lack of efficient utilization of heat transfer from fuel to useful heat consumed in power production.

There has been a great deal of agitation and some action on conservation of natural resources, and it seems to me that the application of the best steam engineering principles, together with plenty of feed-water chemistry, would do much to effect a considerable saving in our national fuel bill and our power equipment.

Too many boiler operators are apt to look at the problem of boiler concentration rather narrowly—for instance, as a matter only

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of scale prevention—forgetting what the delivery of dry, clean steam means. Close discrimination regarding the many problems connected with boiler concentration would do much to increase boiler-plant efficiency.

Some waters are unfit for boiler uses, even in low concentrations, because of inherent corrosive impurities which are not taken out by any of the much-used water-softening processes. We find embittering effects of other impurities, such as dissolved gases; and there are, furthermore, certain reactions taking place as the result of pressure, temperature and concentration in boilers, as illustrated by the decomposition of Na_2CO_3 to $NaOH$ and $NaCOOH$ or salts of other organic acids, which are injurious.

The exhaust steam from engines is often used to heat boiler feed-water with the consequent pollution of the boiler water with oil. If the feed-water is alkaline, serious frothing within the boiler may ensue, which therefore results in entrainment of water and impurities in steam. Oil concentrates within the boiler, deposits upon boiler surfaces, causing intense superheat, with the result of oil-decomposition products that have an adherent sludging action as well as corrosive action. It is therefore logical to effect a separation of the oil from the feed-water before it enters the boiler.

Mr. Kuhman, I believe, stated that a certain user of barium carbonate in the Pittsburgh district gave it up because of the expense in boiler-tube replacements, cost of water treatment, and some trouble within the boiler.

Experience has definitely shown that barium-carbonate treatment of feed-water, in spite of the excessive cost of chemicals used, has resulted in large overall savings. This has been verified time and again by industries which have given up soda-ash feed-water treatment and installed barium-carbonate water-treating plants. The trouble to which Mr. Kuhman draws our attention is probably attributed to oil impurities. Mineral and lubricating oils should certainly be eliminated before reaching the boiler. On the other hand, we are told by Mr. Foulk that "for the prevention of foaming of the sort caused by mixtures of dissolved substances, and finely divided solid matter, castor oil is preeminent."

The measure of efficiency of a boiler plant is the amount of useful heat in the fuel consumed. Factors raising the efficiency are

cleaner heating surfaces, low boiler-water concentration, freedom from corrosive impurities, and dry steam.

"Paying the cost of water softening out of waste" is a modern slogan that may well apply to barium treatment. Mr. Bradshaw has shown how soda-ash and lime or the "zeolite" processes do really raise the boiler concentration. A representative comparison based on actual analysis shows that raw water containing 60 grains per gallon gives by "zeolite" treatment an increase of concentration of 26.6 per cent., there is a decrease of 15 per cent. in the lime and soda-ash treatment, and a decrease of 94 per cent. of boiler concentration with the lime-barium treatment. Mr. Foulk has concluded, after exhaustive researches on

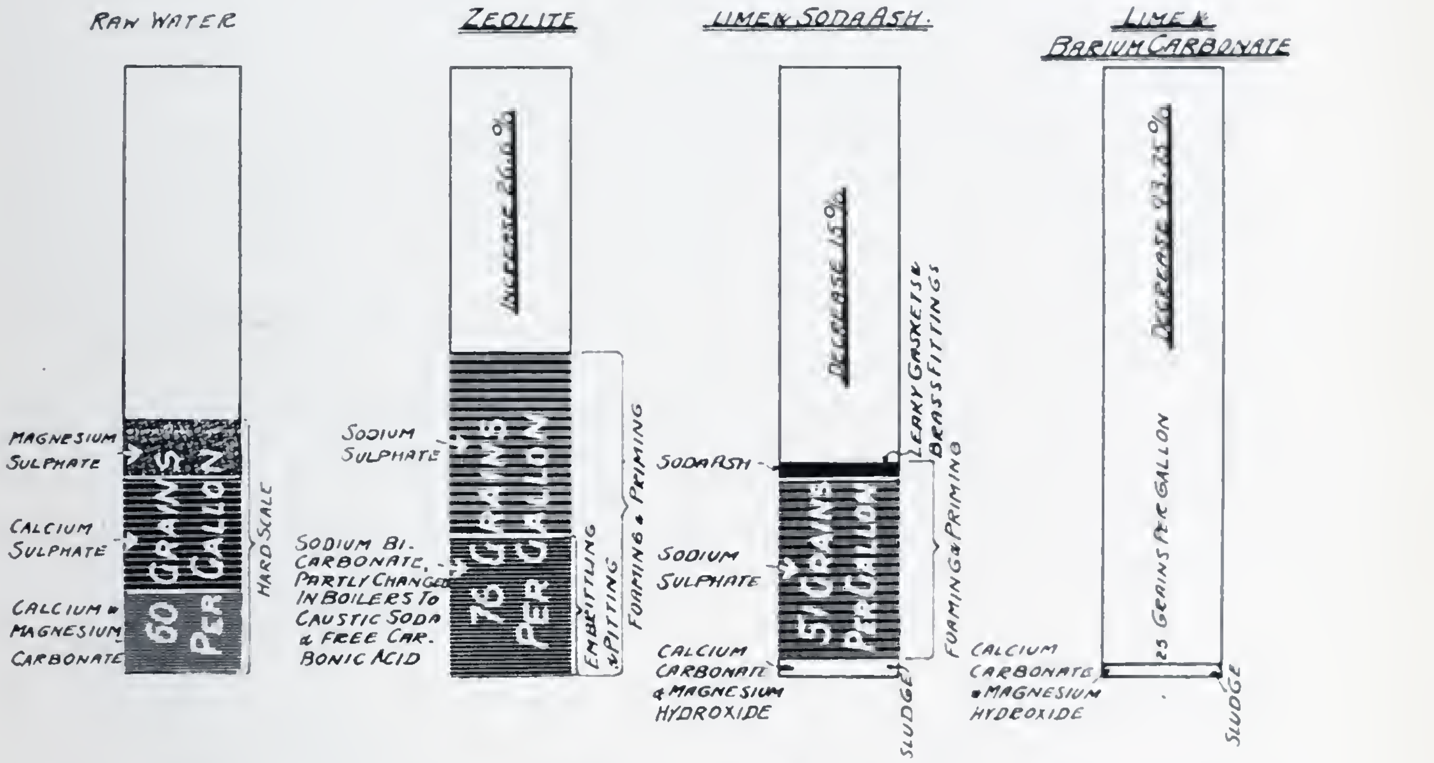

Fig. 5. Effect of Concentration When Using Water-Softening Treatments.

the foaming of boiler water, that "the custom of associating foaming with a high concentration of sodium salts is justified because a high concentration of almost any soluble material creates the fundamental condition for the existence of films, and since film stabilizing material in the form of sludge and loosened scale is nearly always present in a boiler, foaming will occur if the concentration of the sodium salts becomes high."

Fig. 5 shows the effect of concentration when using water-softening treatments—namely, "zeolite," lime and soda-ash, and lime and barium carbonate. In each treatment the same raw water is used.

Mr. R. W. Andrews: May I try to bring out just one other point that is not a formula nor a feed-water reaction, nor a chemical reaction, and that is more or less the history of why concentration is being paid more attention to nowadays? Years ago, concentration was considered simply because it caused scale in the boiler. I think I am pretty safe in saying that fifteen or eighteen years ago practically no one considered anything, except the scale-forming end of it, in the boilers. Feed-water treatment has taken care of that.

Concentration has been taken into account within the past ten or twelve years because it causes foaming and throws out water into the steam lines, and it has been felt that it is the *water* which causes damage to the engines and auxiliaries and the steam-using apparatus.

Nowadays, I think it has come down to a consideration of a further factor which is really vital. To say that moisture in steam causes most of the trouble is about like saying that because, with mosquitoes present, we have disease, the mosquitoes cause the disease. Mosquitoes, of course, only transmit the disease. In the same way, it is not the water in the steam that causes the trouble, but it is what that water carries; and that is another vital reason why concentration should be given more attention, from the standpoint, not of the water that goes over with the steam, but of what that water actually takes over as impurities, and this is much more serious and important than is generally realized.

Mr. K. Von Eltz:* Mr. Bradshaw has shown clearly in his very interesting paper that there is practically no steam which may be considered pure; that is to say, free of water and suspended matter. This is especially true of waters which have been treated with lime and soda-ash. It is the general impression that such water, if the hardness has been reduced to three or even two grains per gallon, is entirely suitable for boiler feed. But, as Mr. Bradshaw points out, the total amount of minerals in solution in such a water is actually greater after treatment than before, because the atomic weight of the sodium sulphate formed is greater than that of the incrusting and corrosive sulphates which are eliminated. This applies also to the water treated with "zeolite" where conditions are aggravated, because

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here the calcium and magnesium carbonates are changed into soluble sodium bicarbonate.

Mr. Bradshaw mentioned one treatment where the formation of sodium sulphate is avoided, namely, barium; but he pointed out the fact that the cost for this treatment is much higher and that it is difficult to remove the very fine, precipitated barium sulphate. Of course, if the barium sulphate is left in the water, it will form a hard scale in the boilers. This trouble has been frequently experienced if the boiler water was treated internally with barium hydrate—a method of treatment which of late years seems apparently to have been given up on account of the high cost of barium hydrate. A much more satisfactory reagent is the barium carbonate, because this is insoluble in water that does not contain corrosive or incrusting sulphates. If used in a regular barium water softener, it is possible to pass all the raw water through the barium carbonate, sufficient for a 12-hour or 24-hour run, where only so much of it will be changed into barium sulphate as corresponds to the incrusting and corrosive sulphates present in the raw water, and thus an overtreatment is not possible. This is of especial importance for waters of a variable hardness, as is the case in the Pittsburgh district. This automatic dosing feature is not possible with barium hydrate. Furthermore, caustic lime is formed, which may render the treated water caustic to an undesirable degree when the calcium and magnesium contents of the raw water are less than corresponds to the caustic lime formed.

Barium carbonate is practically insoluble, and barium sulphate which results from the treatment is absolutely insoluble; therefore, the treated water will contain only a small residue of calcium carbonate and magnesium hydroxid, provided that the barium sulphate formed is retained in the apparatus. This can be, and is, done if the softener tank is designed so that certain speeds of the water are maintained which will allow the greater part of the precipitated barium sulphate to settle out. In addition, there is required a large and efficient sand filter.

As stated before, a water treated in such an apparatus with barium carbonate will contain no matters in suspension nor soluble salts formed by the treatment, with the exception of a small amount of calcium carbonate or magnesium hydroxid. If these two salts are

present practically alone in the treated water, they will form in the boilers a soft sludge and a very thin coat, comparable to whitewash. This coating safeguards against corrosion and pitting, but it does not adhere firmly to the boiler shell and tubes and, therefore, can easily be washed off.

Mr. Ludgate asked what the price of the barium carbonate treatment would be. He understood that it was about six times the cost of soda-ash. It is true that, on account of the greater atomic weight, about twice as much barium carbonate as soda-ash has to be used, and that the pound price for the former is higher than for the latter; and, therefore, the barium-carbonate treatment will be more expensive than the soda-ash treatment. The cost for the lime is the same for both. The true criterion for a comparison of costs of the different treatments is not the cost per 1000 gallons, but the cost of converting this amount of water into actual steam. If a certain amount of the treated boiler water is wasted, either through frequent blowing off in order to keep down the concentration, or through wet steam, this water represents a loss, not only in fuel, but also in efficiency.

The barium carbonate treatment is to some extent used in the East; but, since no specially designed apparatus was used, the benefits of this treatment could only partly be materialized. On the other hand, in the Southwest and abroad, regular lime-barium water softeners have been used for a number of years with very good success. The advantages of the barium carbonate over soda-ash are especially appreciated by users who replaced the soda-ash by barium-carbonate softeners.

SOME ASPECTS OF OXYGEN ENRICHMENT OF COMBUSTION AIR IN HEATING-FURNACE PRACTICE*

By W. C. Buell, Jr.†

This paper presents a study of the theoretical, economic and operating factors that will be encountered when free oxygen is added to the air and fuel used in developing heat in industrial furnaces.

The subject of the advantages to be gained by the oxygen enrichment of atmospheric air for combustion practice has been discussed for years, and recently considerable new discussion has been awakened by the release of the report‡ of a committee investigating the subject. This report, issued by the United States Bureau of Mines, sets forth certain advantages to be derived from the system, particularly with regard to its application to blast-furnace operation, and shows possible economies.

The cost of oxygen which heretofore has been assumed to be great has probably prevented serious consideration of the application, but the findings of the committee on this point (as indicated in the following quotation from page four of the above report) are of sufficient importance to warrant the possibilities of the use of the system being given most serious consideration:

"This committee has made a thorough survey of the existing processes for the manufacture of 99 per cent oxygen. The conclusions reached by this survey are that the comparatively small demand for the product has prevented the installation of large units suitable for metallurgical processes, with corresponding economies, and by far the greater proportion of the present cost of oxygen represents the cost of transportation, storage and service. Large oxygen manufacturing plants can be built to serve metallurgical purposes directly, which, by virtue of their large production and correspondingly increased efficiency, together with the fact that no compression in cylinders, storage, transportation, or service will be required, will be capable of delivering oxygen for the processes at a cost not to exceed $3 per gross ton. In other words, the committee finds that the oxygen industry is now able to make plants for supplying large quantities of oxygen to metallurgical industries at low cost."

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†Mechanical Engineer, Pittsburgh.

‡The Use of Oxygen or Oxygenated Air in Metallurgical and Allied Processes, by W. F. Davis. 1923. (U. S. Bureau of Mines. Reports of Investigations Serial No. 2502.)

At \$3 per gross ton the volume cost of oxygen is

$$\frac{\text{cost per gross ton} \times \text{cubic feet}}{\text{weight in pounds} \times \text{cubic feet } O_2 \text{ per pound}}, \text{ or } \frac{300 \times 1000}{2240 \times 11.208}$$

= 11.95 cents per 1000 cubic feet at standard conditions.

Oxygen enrichment works advantageously in combustion practice in two principal ways; first, by accelerating the rate of combustion, permitting the fuel to be burned in the minimum volume; and, second, by increasing flame temperature through the release of an equal amount of heat to a smaller volume of the products of combustion.

Combustion men generally will admit the desirability of the foregoing in general practice and their necessity (or the preheat equivalent) in a number of high-temperature operations. In some degree—and comparatively, as will be shown later—the two advantages will be found in the use of preheated air.

It is necessary that a number of comparisons and analyses be made, and it is considered best to work throughout with a simple fuel. The fuel selected is Pittsburgh natural gas of the following composition:

CH_4	(methane)	80.4%
C_2H_6	(ethane)	18.7%
N_2	(nitrogen)	0.9%
Total		100.0%

The heating value (available) is 966 B.t.u. The air required for combustion is 10.822 cubic feet per cubic foot of fuel.

This fuel was selected in view of the relative simplicity of the calculations; and, further, that with carbon at 75.7 per cent. and hydrogen 23.5 per cent., it is fairly representative of a number of fixed fuels.

In this study five conditions will be studied and compared. The conditions are as given in Table I:

TABLE I. CONDITIONS OF ENRICHMENT

Condition stated	Oxygen in cubic feet per cubic foot of gas: Added	In air	Ratio
No enrichment	0.000	2.262	
25% enrichment	0.4525	1.8095	1 : 4
50% enrichment	0.754	1.508	1 : 2
75% enrichment	0.972	1.290	1 : 1.33
100% enrichment	1.131	1.131	1 : 1

From the data in the above table are derived partial combustion data shown comparatively in Table II:

TABLE II. PARTIAL COMBUSTION DATA FROM TABLE I

Condition stated	Cubic feet per cubic foot of gas — Required for combustion — Added oxygen	Air	Products of combustion — CO_2	H_2O	N_2	Total	Percentage of CO_2 in dry products of combustion
No enrichment	0.0000	10.822	1.178	2.169	8.569	11.916	12.1
25% enrichment	0.4525	8.672	1.178	2.169	6.869	10.216	14.65
50% enrichment	0.754	7.211	1.178	2.169	5.709	9.056	17.1
75% enrichment	0.972	6.183	1.178	2.169	4.899	8.246	19.4
100% enrichment	1.131	5.414	1.178	2.169	4.289	7.636	21.55

The graphic study in Fig. 1 shows the temperature-calorific values of the products from the perfect combustion of one cubic foot of Pittsburgh natural gas and the air required for the perfect combustion of one cubic foot of the fuel (10.822 cubic feet of air).

In this graph (curve *A*), the abscissæ show the temperature in degrees F., and the ordinates show the B.t.u. per cubic foot of gas burned (curve *A*), or B.t.u. in the air for its combustion (curve *B*). The curve *A* gives the available sensible heat remaining in the products of combustion at any temperature, and curve *B* the sensible heat in the air for the combustion of one cubic foot of gas; or, if the B.t.u. content of the products of combustion or the air is known, the resulting temperature may be read.

Throughout this study, all conditions used are based upon the fuel being burned with the exact volume of air necessary to produce perfect combustion.

The following example will suffice to show the use of the curves of the three included figures: If a line *C* be projected from temperature 2125 degrees to *A*, and then to the ordinate by line *D*, we will find the quantity of heat (560 B.t.u.) remaining in the products of combustion at that temperature. Or if the B.t.u. content of the products of combustion is known we may project from the ordinate in reverse order and find its temperature. Thus, if line *E* be drawn from 966 B.t.u. to *A*, and vertically downwards by *F*, we will find the temperature to read 3275 degrees; and in this case the figure will show the flame temperature as with cold fuel and cold air, for the

B.t.u. figure represents the total available heat of the fuel. Again, if the temperature of the air is known and the line *G* is extended upwards to *B* and then horizontally to *H*, the ordinate will show the heat carried in the air and which may be added to the combustion reaction. The lines *G* and *H* as drawn give 250 B.t.u. with the air preheated to 1250 degrees. This figure when added to the 966 B.t.u. originally contained in the fuel gives a new and total calorific for one cubic foot of natural gas of 1216 B.t.u. If from this new calorific value the horizontal line *J* be extended to *A*, and downward by *K*, the new flame temperature 4075 degrees will be found for cold fuel and preheated air.

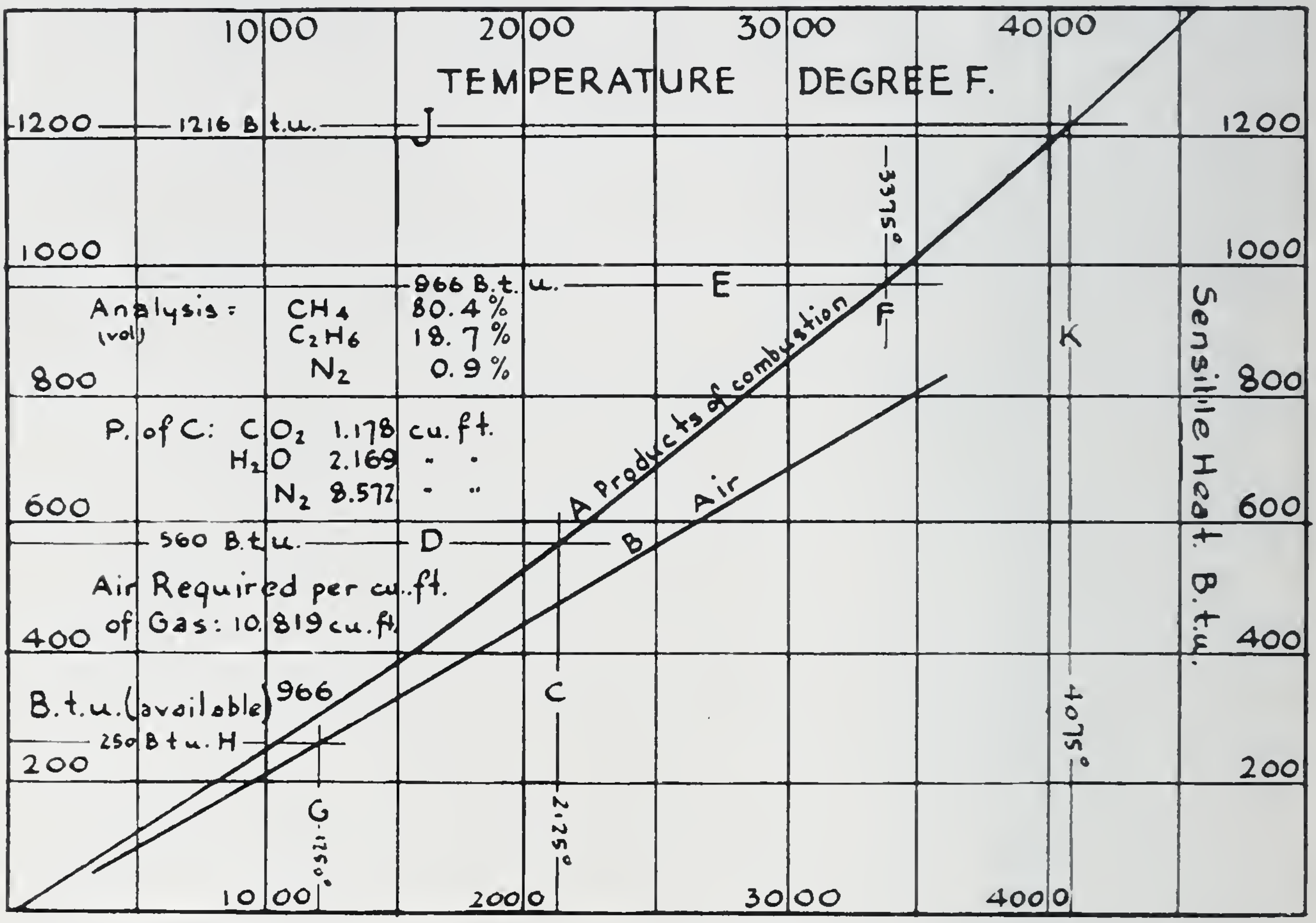

Fig. 1. Sensible Heat in Products of Combustion of One Cubic Foot of Pittsburgh Natural Gas, and in Air Required.

A thorough understanding of the foregoing method is necessary in order to interpret the comparisons and deductions which will be made.

Flame temperature is a function of the sensible heat contained in the products of combustion and, accordingly, if the volume of products of combustion from the combustion of one unit of fuel is divided into the total available heat of the fuel, the result will give the total heat contained in one cubic foot of products of combustion.

The effect of enrichment in increasing the sensible heat contained in one cubic foot of the products of combustion is worked out below, and the curves in Fig. 2 have been plotted from the data here given:

TABLE III. EFFECT OF ENRICHMENT

	Enrichment				
	None	25%	50%	75%	100%
Volume of products of combustion in cubic feet	11.916	10.216	9.056	8.246	7.636
Total heat, B.t.u.	966	966	966	966	966
Heat per cubic foot of combustion products	81.1	94.6	106.7	117.1	126.5

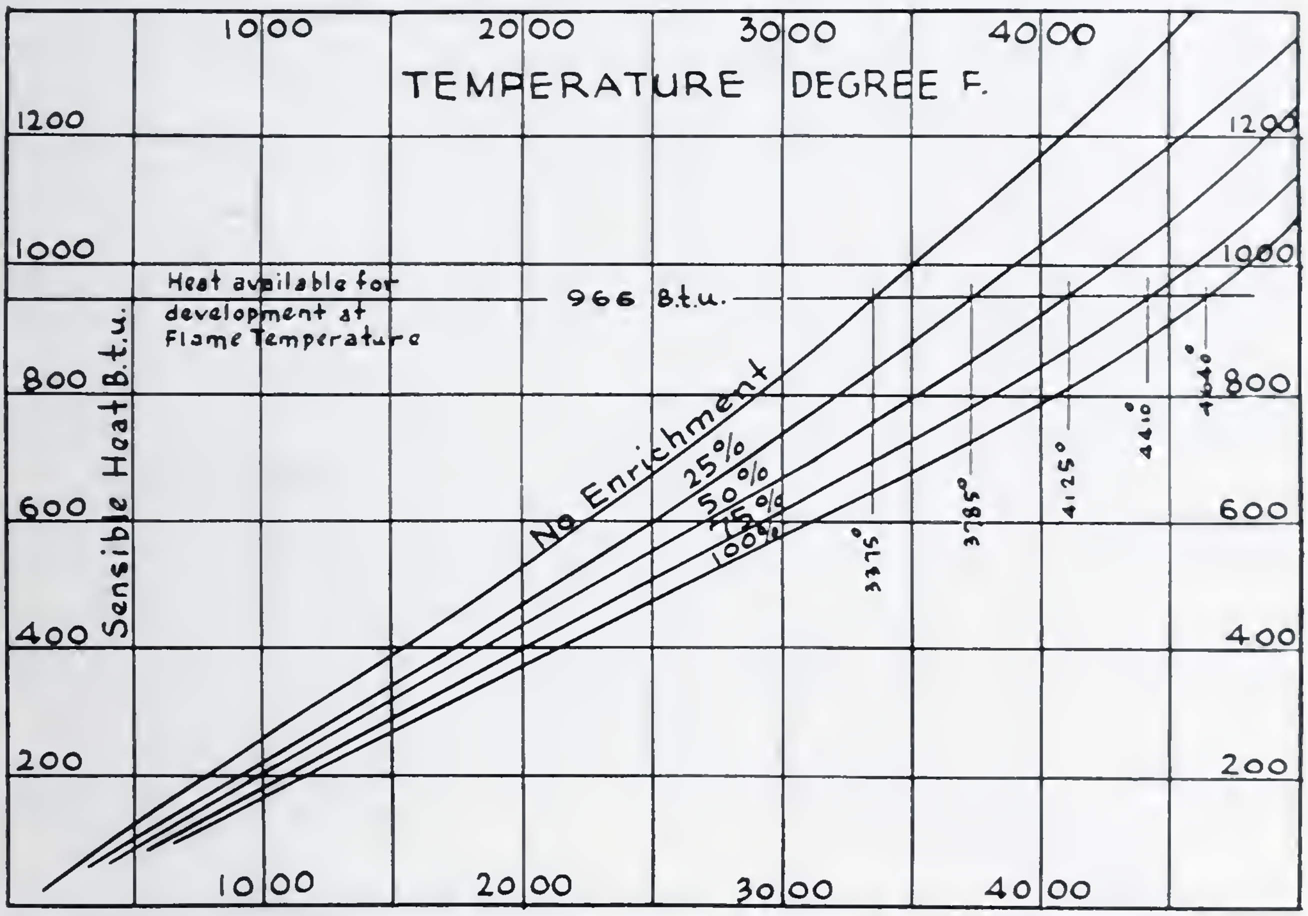

Fig. 2. Sensible Heat in Products from Combustion of One Cubic Foot of Pittsburgh Natural Gas with and without Oxygen Enrichment.

It therefore stands to reason that to accomplish equal flame temperature by other methods, any products of combustion must contain the same approximate amount of sensible heat—approximate, as there is some variation of the specific heat of the components that make up the products of combustion.

The curves in Fig. 2 are for the oxygen enrichment conditions as noted in connection with each. The curve "No Enrichment" is identical with curve *A*, Fig. 1.

The horizontal co-ordinate at 966 B.t.u. (total calorific value of the fuel), if followed, will give the theoretical flame temperature for

the particular condition of enrichment. The difference in flame temperature is due entirely to the fact that in each case a similar quantity of heat is carried in a varying volume of the products of combustion.

In Fig. 3 the curves give the temperature-calorific value characteristics of the air needed for combustion in the same manner in which the curves in Fig. 2 give the characteristics for the products of combustion, and under the same ascribed conditions. The "No Enrichment" curve in Fig. 3 is the same as curve *B*, Fig. 1. The outstanding feature of the comparison is the rapidly decreasing amount of

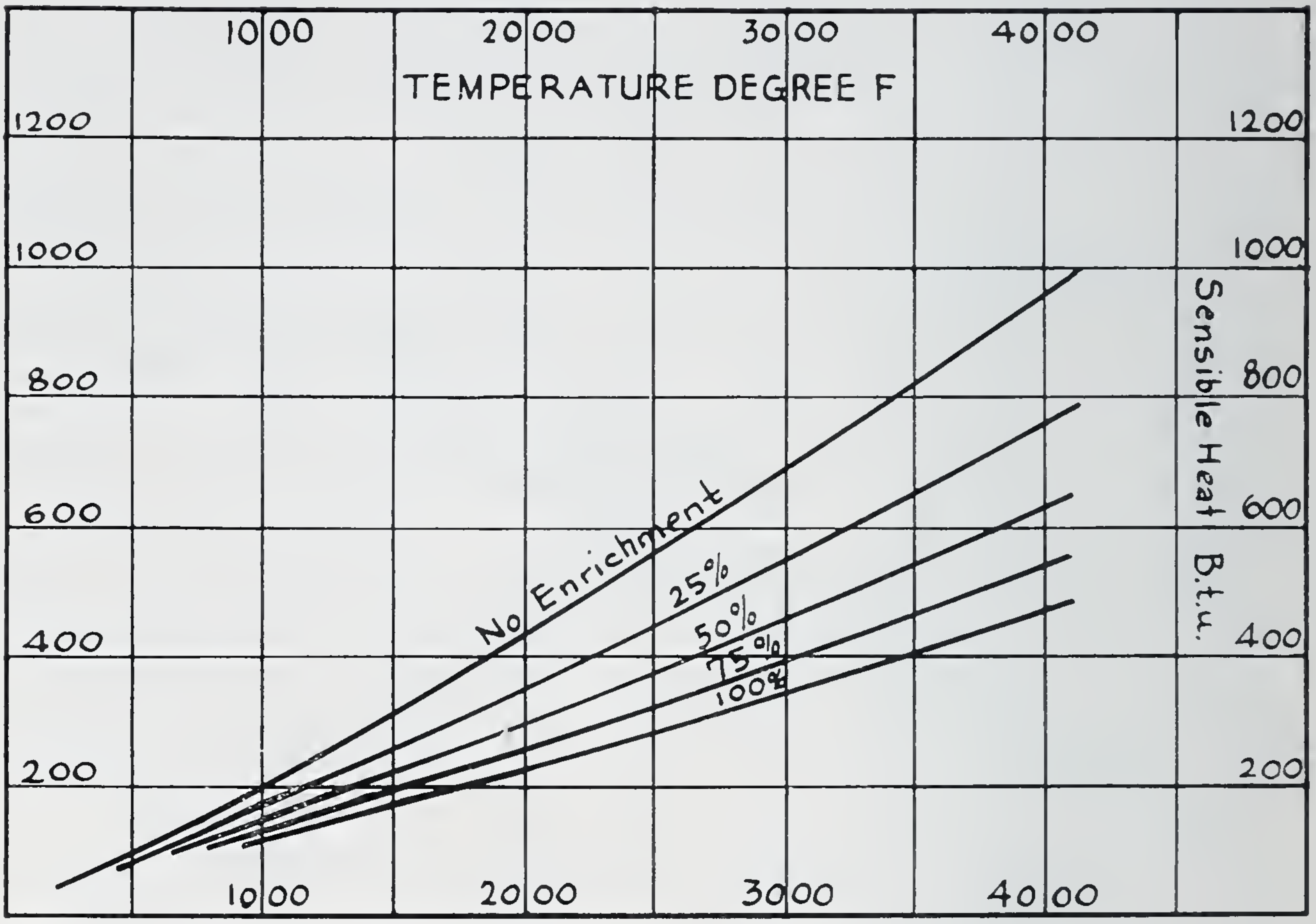

Fig. 3. Effect of Oxygen Enrichment on Thermal Capacity of Air Required for Burning One Cubic Foot of Pittsburgh Natural Gas.

sensible heat carried in the heated air as the enrichment ratio increases. Of course, this condition comes from the smaller volume of air necessary as enrichment increases.

It has been shown in Table III and its accompanying text that for equal flame temperature the products of combustion must carry an equal amount of sensible heat per cubic foot. In order to determine what this will be for the all air-fuel mixture it has been necessary to calculate back from the "Heat per cubic foot of combustion products,"

Table III. Working back from these figures, those of Table IV have been found, and it is seen that a considerable degree of preheat is necessary in the air to equal the effect produced by enrichment.

TABLE IV. EFFECT OF ENRICHMENT

	Enrichment				
	None	25%	50%	75%	100%
Heat in fuel, B.t.u.	966	966	966	966	966
To be added as sensible heat in air, B.t.u.	....	180.9	305.0	428.9	541.0
Total heat, B.t.u.	966	1147	1271	1395	1507
Preheat temperature of 100% air	....	875°	1440°	1950°	2450°
Volume of products of combustion in cubic feet	11.916	11.916	11.916	11.916	11.916
Heat per cubic foot of combustion products	81.1	94.6	106.7	117.1	126.5

From the joint use of the curves in Fig. 2 and 3, and the values in Table III, it is a simple matter to calculate the degree of preheat necessary to equal the flame temperature of any ratio of oxygen enrichment. For instance, the horizontal line of 966 B.t.u. of Fig. 2 shows the flame temperature with no enrichment and with 100 per cent. enrichment to be 3375 degrees and 4640 degrees, respectively. A line projected vertically from the latter point to bisect the "No Enrichment" curve will show that with no enrichment it would be necessary that the fuel contain 1400 B.t.u. to give the equivalent flame temperature. It would seem, therefore, that the 434 B.t.u. should be added to the original fuel value to give an equal effect; but, actually, more heat must be added to compensate for the additional volume of products of combustion from the all air-fuel mixture. As a matter of fact, 541 B.t.u. must be added in the air by preheat to reach the flame-temperature figure of the 100 per cent. enrichment condition; and proportionally for all other conditions. A number of the conditions just touched upon are shown in some detail in Table V.

TABLE V. RELATION BETWEEN PREHEAT AND FLAME TEMPERATURE

Condition stated	A	B	C	D	E	F
No enrichment	3375°	Unity			966 B.t.u.	
25% enrichment	3785°	12%	145 B.t.u.	16.0%	1110 B.t.u.	875°
50% enrichment	4125°	22%	259 B.t.u.	27.5%	1225 B.t.u.	1440°
75% enrichment	4410°	31%	349 B.t.u.	38.0%	1315 B.t.u.	1950°
100% enrichment	4640°	37%	434 B.t.u.	45.5%	1400 B.t.u.	2450°

Column A. Calculated flame temperature, cold fuel, air and oxygen.
Column B. Per cent. increase in flame temperature by enrichment over fuel-air mixture.
Column C. Equivalent calorific value added to fuel, indicated from increase in flame temperature.
Column D. Per cent. equivalent increase in calorific value by enrichment.
Column E. Total new and equivalent calorific value of one cubic foot of natural gas.
Column F. Preheat temperature of 100 per cent. air for combustion necessary to equal flame temperature A.

If the cost of oxygen is assumed as 12 cents a thousand cubic feet, and that of the gas fuel as 30 cents, then the total cost of oxygen and gas as per the ascribed conditions will be as shown in Table VI.

TABLE VI. COST OF OXYGEN AND GAS

Condition stated	A Cubic feet of oxygen required	B Cost of oxygen	C Total fuel cost	D Per cent. increase
No enrichment	None	None	30.000c.	Unity
25% enrichment	452	5.424c.	35.424c.	18%
50% enrichment	754	9.048c.	39.048c.	30%
75% enrichment	792	11.664c.	41.664c.	39%
100% enrichment	1131	13.572c.	43.572c.	46%

The percentage of increased fuel cost, as shown in column D, very nearly duplicates the figures of increased calorific value in column D, Table V. Therefore, if economy is to come from the use of enriched air, it must come from other factors. It will be shown that a considerable saving in fuel cost will be found in other items.

It is inherent in heating-furnace practice that the products of combustion leave the furnace at relatively high temperature and it is usual to find 40 to 60 per cent. of the total heat of the fuel represented therein. Recuperation or regeneration is often employed to salvage a part of this heat; and, in the best practice, these devices will return to the air for combustion about 40 per cent. of the heat in the products of combustion. Recuperators and regenerators are quite costly; they are of considerable size; they ordinarily require setting in a considerable excavation; and, at best, they need some attention. In present practice they are a great economy, and, on many high-temperature operations, a necessity. The ultimate temperature of the products of combustion leaving a furnace is a function of several controllable factors, such as hearth length, width, loading, operating methods, etc.

Bearing in mind that the volume of products of combustion per unit of fuel decreases rapidly as enrichment increases, until at 100

per cent. enrichment the volume of the products of combustion is only 64 per cent. of the all-air mixture, it stands to reason that with a furnace of equal length and operating under similar conditions, the exit temperature will be lower, or a considerably shorter furnace may be used for the same exit temperature. Owing to the difference in the thermal capacity of the products of combustion, a considerable saving in fuel cost will be found from enrichment at equal exit temperatures.

The thermal capacity of the products of combustion at selected temperatures and under the ascribed conditions, as well as the percentage of total heat carried, is given in Table VII.

TABLE VII. THERMAL CAPACITY OF PRODUCTS OF COMBUSTION

Condition stated	Temperature of products of combustion, degrees F. 1000	1500	2000	2500	Ratio
No enrichment	348 B.t.u. 36.0%	380 B.t.u 39.2%	530 B.t.u. 54.7%	680 B.t.u. 70.0%	100%
25% enrichment	303 B.t.u. 31.5%	335 B.t.u 34.7%	460 B.t.u. 47.8%	590 B.t.u. 61.0%	87%
50% enrichment	253 B.t.u. 28.4%	300 B.t.u 31.2%	410 B.t.u. 42.5%	530 B.t.u. 55.0%	78.5%
75% enrichment	252 B.t.u. 26.2%	275 B.t.u 28.6%	385 B.t.u. 40.0%	490 B.t.u. 50.9%	72.5%
100% enrichment	235 B.t.u. 24.4%	255 B.t.u 26.5%	360 B.t.u. 37.4%	460 B.t.u. 47.8%	67.5%

In Table VII, the B.t.u. figures give the total heat of the original 966 B.t.u. of the fuel remaining in the products of combustion at the indicated temperature. The percentage figure under the B.t.u. value is the percentage of B.t.u. remaining in the products of combustion.

By comparison of Tables V and VI, it has been shown that the cost of enrichment is just about offset by the increase in available calorific value. The figures of Table VII give what probably will be the greatest single item of savings coming from the use of enrichment. The net heating cost with 100 per cent. enrichment will be only about two-thirds the cost of simple furnace operation, but again this savings may be offset by good recuperative or regenerative practice. However, the capital charges and up-keep cost of the preheat equipment will be saved, and construction limitations overcome. These items are, in themselves, considerable and their elimination will weigh heavily in favor of enrichment.

A number of other economic advantages will be found through the use of enrichment. The furnace structure will be much smaller

in cross-section, and bridge walls, ports, and other designs for mixing will be absent. With smaller cross-sectional areas, the contact between the products of combustion and the metal will be more intimate and consequently a greater and more efficient heat transfer may be anticipated.

All of the foregoing will react most favorably on heating cost, and it is the writer's conservative impression that, as against the best simple furnace practice, the cost will be cut in half, and as compared with the best recuperative or regenerative practice the cost of heating will be about 75 per cent.

The writer does not anticipate that there will be any serious limitations in design. At the minute it seems desirable that the fuel, air, and oxygen be introduced through a relatively large number of burners. Owing to the accelerating effect of the oxygen on the combustion reaction, firing may be accomplished without the use of a refractory surface (such as an arch) or an obstruction (such as a bridge wall) to break down velocities. With proper combustion chamber design, and correct application of combustion equipment, no undue wear on the refractories need be feared. With 100 per cent. enrichment and its flame temperature of 4640 degrees, a preheat of 2450 degrees is indicated. Although seldom, this figure is occasionally achieved, and it is accordingly safe to say that furnaces are to-day actually operating at the maximum temperatures considered. Combustion conditions within the furnace may be as the operator wills and any condition of present practice as regards velocity, density, etc., may be accomplished.

As to the effect of the process on the metal, the total volume of carbon dioxid and water vapor will be the same with or without enrichment. With enrichment, the percentage of both of these components carried in the products of combustion increases. The total percentage of carbon dioxid (except with producer gas) at 100 per cent. enrichment will be but little more than with a coke fire, and total water vapor percentage will certainly be less than is the case in present practice where oil or tar is atomized with steam. It accordingly seems reasonable to assume that there will be no unfavorable comparison.

This study has dealt entirely with natural gas. The results with any other common fuel will be substantially parallel. As to com-

parative cost, natural gas (966 B.t.u.) at 30 cents per thousand cubic feet is the equivalent of oil (144,000 B.t.u.) at 4.5 cents per gallon; coke-oven gas (450 B.t.u.) at 14 cents per thousand cubic feet; and producer gas, 70 per cent. producer efficiency, with coal (13,000 B.t.u.) at $5.65 per ton in the producer.

The quantity of oxygen that may be required for even a relatively small furnace is quite staggering to those bottling it for commercial use.

If a production of 10 tons of steel per hour in a continuous furnace is assumed, with a fuel consumption of 2000 cubic feet per ton of metal, than the requirements for oxygen are in accordance with the figures of Table VIII.

TABLE VIII. OXYGEN REQUIREMENTS IN CONTINUOUS FURNACE

Condition stated	Cubic feet of oxygen required Per minute	Per hour
No enrichment	None	None
25% enrichment	151	9,050
50% enrichment	251	15,080
75% enrichment	325	19,440
100% enrichment	377	22,620

In this study the writer has tried to cover the more important considerations of the problem, but the subject is worthy of a much more voluminous treatise. It was the writer's thought that this might serve to stimulate an interest in the subject and to put additional minds to work. The subject is of great economic interest to large users of fuels, and the day is probably not far distant when a decided reduction in heating costs must be accomplished. Oxygen enrichment is probably far from a cure-all, but such investigation as the writer has made indicates that a very remarkable reduction will come from its adoption. All other investigators of the subject report a similar belief, and as the belief becomes more general the possibilities of the first installation are more nearly realized.

DISCUSSION

Mr. W. P. Chandler:* Mr. Buell is to be congratulated on the concise manner in which he has shown the comparisons of results to be obtained in heating furnaces through oxygen enrichment and through preheated air. The graphs presented in the paper make the solution of possible heating-furnace performance very simple, if natural gas be used as fuel.

A great many problems will have to be solved by the company which pioneers in the field and installs an oxygen plant for supplying this commodity. A comparison of first costs of the oxygen plant and the furnace recuperator or regenerator undoubtedly will deter a great many engineers from making the initial step. Added to this is the uncertainty of the benefits to be derived, or at least of the changes in furnace construction required for the new method of operation.

If we consider a typical continuous heating furnace, operating on relatively small billets and preheating the air for combustion in either a recuperator or regenerator we have probably as efficient a furnace as any that is operating at present. If the operation of such a furnace were changed so that oxygen-enriched air were supplied instead of preheated air, and the recuperator were eliminated, a smaller volume of products of combustion would result, with corresponding lower velocities and lower rates of heat transfer, so that the temperature at the back of the furnace probably would be higher. Under such conditions some means of conserving the heat leaving the furnace should be provided, either in the form of recuperator or waste-heat boiler. If the recuperator were used for the air before enrichment the flame temperature would be so high that brickwork would not last. However, some balance might be worked out between the amount of enrichment and the temperature of the waste gases in the stack.

Another item which deserves careful study is a comparison of the maintenance and operating costs for the recuperator and for the oxygen plant. The latter would appear to be considerably higher, since a well-constructed recuperator requires very little attention.

With the higher percentage of oxygen in the air for combustion, greater care in regulation would be required to prevent an increase in scale loss in the furnace.

*Assistant Fuel Experimental Engineer, Carnegie Steel Co., Duquesne, Pa.

A consideration of the whole field of oxygen enrichment seems to indicate that the first practical demonstrations of the use of oxygen-enriched air would be made in some other field of steel-plant operation than the heating furnace.

Mr. A. E. Blake:* There are those who maintain that the use of air enriched with oxygen, or of pure oxygen, in connection with metallurgical operations aside from present uses in blow-torch work, would be an absurdity, owing to the enormous chemical activity of oxygen, to say nothing of the expense of its production and the cost of an installation for that purpose. These people are undoubtedly highly justified in their stand. Nevertheless, this paper of Mr. Buell's gives opportunity for many interesting speculations such as often result in a great deal of good by calling attention vividly to actual present-day problems.

One of these problems of continual interest which strikes the reader of Mr. Buell's paper is that of refractories. Nothing has been said in the paper concerning that phase of the use of oxygen, but I am sure we are all agreed that, if the conditions pictured by Mr. Buell could be realized, the already insistent demand for refractories which will stand high temperatures and the action of fused silicates at such temperatures would be increased tenfold.

It seems to me that oxygen enrichment, or the use of pure oxygen, would be chiefly confined to high-temperature melting operations. One reason for this is that medium and low-temperature operations, including those up to 1800 degrees F., are accomplished with sufficient thermal efficiency to make the practice of oxygen enrichment not worth while. This would rule out a good percentage of factory and mill heating operations in the steel industry, including the bolt, nut, and rivet trade, the sheet business, galvanizing and tin-plate business, etc.; also the processes of annealing and decorating in glass-works, and many operations in the aluminum industry.

It seems to me that great difficulties would have to be overcome in applying the scheme to some of the higher temperature operations, such as might be found in rolling-mills and heavy forging operations, where the temperatures required in the metal must be exceedingly uniform in order to secure a flow of metal satisfactory to the design

*Pittsburgh Representative, U. G. I. Contracting Co.

of the rolls, or to avoid the cracking of heavy forgings, due to too great a difference in the temperature from the outside to the interior, which one could expect from carrying a greatly increased thermal head in the furnace, against the pieces being heated. It can be argued, of course, that the thermal head can be kept down to what it is at present, with the use of less fuel. Then it would remain to be seen if the saving which Mr. Buell has figured would result. There would be the liability, however, at all times, that it would be still more difficult to stay under the safety limit, which is easily passed under present conditions. This would be especially true if the zones of combustion are to be brought close to the work, as Mr. Buell suggests in his paper.

If recuperation or regeneration is worth while at present, the arguments for such practice will not be greatly changed by the introduction of oxygen, especially in high-temperature work, and the size of recuperators or regenerators could probably be less than at present.

The pottery industry does not seem to offer much of a field for this idea, because of the great care requisite in slowly increasing the temperature of ceramic ware through the so-called water-smoking period, to prevent injury through too rapid loss of moisture; also the dangers of overheating locally, and difficulty in finishing a kiln without great difference between the final temperatures reached in the ware in various portions of the kiln. More promise is found in the application to tunnel kilns, but these are effecting so great a saving in themselves as to make it difficult for their owners to risk injury to a very costly installation, or to contemplate installations with special refractories throughout, which might be more or less experimental.

In view of the foregoing, I feel sure that if such a practice could be attractive at all, it would first succeed in melting operations where one would not be troubled by the conductivity of the charge being too slow to cause any injury, and where the efficiencies now obtained are far from being comparable with low-temperature operations. It seems to me that here the chief limitation would be the quality of refractories in their ability to withstand plain high temperature, and the high-temperature attack of molten oxids and silicates. The use of the temperatures referred to by Mr. Buell would bring the metallurgist into a brand-new field of chemical activity, approaching that which has already been experienced in electric furnaces in the steel industry. The steel maker would be able to utilize some of the experi-

ences of the electric-furnace man, but the glass man would be lost and have to explore the whole way.

Mr. Buell's paper reminds me of an idea which I had some time ago of reducing producer gas to the liquid state, and fractionating it in modern heat-exchange apparatus designed especially for that purpose, in order to eliminate in that way the inert or non-combustible portion. To simplify that problem, I had it in mind to start with producer gas from coke, and the result, of course, would be a high-duty gas of approximately two-thirds to three-fourths carbon monoxid, and one-third to one-fourth hydrogen. The theoretical reaction temperature would be in the neighborhood of 4200 degrees F., and the general properties very similar to those of blue water-gas. Coke producer gas of 130 B.t.u. has a theoretical reaction temperature of somewhere near 3150 degrees F. The gain in thermal head would be considerable, regardless of whether preheating were practiced or not.

A ton of high-grade coke yields about 15,000,000 B.t.u. as blue water-gas, and 20,000,000 B.t.u. as coke producer gas in a modern producer-gas installation. There is a margin of 5,000,000 B.t.u. available therefore for energy for liquefaction. Furthermore, low-grade coke, obtainable very cheaply, can be used as a source for the producer gas. If one is to consider liquefaction equipment for oxygen and he happens to be intending to apply producer gas, he might serve the same purpose by eliminating oxygen equipment and designing to use that which would answer for the producer gas.

I should like to commend Mr. Buell for his very interesting paper.

Mr. W. C. Buell, Jr.: Mr. Chandler in his discussion intimates, as I take it, that the enrichment characteristics would be radically different throughout the study if a fuel other than natural gas were used—that another fuel would not lend itself so easily to the quantitative analysis that I carried through. In regard to that particular point I can say that you can work through the study with any fuel in exactly the same way (modifying the data, of course), and the results will be comparable in every respect.

It was not my idea that you could take the oxygen process and apply it to the existing furnace and secure the best results. You must make some changes. The cross-section would decrease, we will main-

tain approximately the same velocity of flow and rate of heat transfer, and which instead of being lower as he intimated, should be greater, because the products of combustion would be in more intimate contact with the material at all times.

He mentioned the cost of up-keep. As I understand it, the figure of $3 a ton for oxygen included up-keep cost.

Mr. Blake dwells at length on the refractories. With our usual fuels and relatively slow combustion, especially with cold air, it is necessary in many cases that the mixture impinge on the refractories in order that the initial velocities may be broken down to the point where the speed of back-fire becomes equal to the velocity of the fuel mixture. With oxygen enrichment, the rate of combustion will be so much accelerated that it will not need a bridge wall to break down the initial velocity.

You can introduce flame into an open space and instead of having a fan-like flame form on the under side of the arch you will have a ball of highly incandescent fire; and, by introducing the mixture through a number of relatively small ports, you can produce a continuous cylinder fire without any necessity for the mixture to come in contact with the refractories. Consequently, the refractories will be subject only to the effect of radiant heat and not to the erosive effect of the flow of products of combustion at high temperature.

Mr. Blake also dwells on the smaller installations. I have not considered them. The largest fuel saving will be made in mill installation for a long time to come. Later, we will have to pay more attention to the smaller furnaces. Just now we can do more good by cutting the cost on large installations where great tonnage is produced and thus decrease the heating cost in our basic manufactures.

Economically the medium and low-temperature operations Mr. Blake mentions will show the proportionately greatest return. If, as has been shown in Table VI, the quantity of the heat in the products of combustion can be materially reduced by enrichment, the necessity for the relatively high-cost recuperator in the small furnace is absent, and a high economy accomplished without the recuperator.

Mr. Blake has also given some thought to the fractionation of producer gas and the elimination of nitrogen. Possibly he can have a double plant constructed and take nitrogen out of the gas in one and the combustion air in the other.

Mr. John S. Unger:* I do not have any particular discussion to make of the paper. I would just like to ask if the author knows of any heating-furnace installation in operation at the present time using enriched air?

Mr. W. C. Buell, Jr.: No.

Mr. John S. Unger: I just wanted to make certain of the situation. I have been interested in the use of oxygen for quite a good many years. At one time I was very enthusiastic about it, but when I began to study it I lost part of my enthusiasm. There has been a great deal written on this subject. The last article that appeared was a symposium of the American Institute of Mining and Metallurgical Engineers at their meeting in February, 1924. It is worth reading for those who are interested in the subject. There have been arguments in favor of the use of oxygen and some against it. The advocates of oxygen might clear the situation very materially by furnishing a life-size, real example of what oxygen will do. What I mean is, rather than theorizing (of which a great deal has been done), they should try to put in successful operation one furnace which would furnish positive data.

A blast-furnace in Belgium was operated for a short time on enriched air. An experiment was made in Canada with a small experimental blast-furnace and a very small experimental blast-furnace was run with pure oxygen. From what I was able to learn of these trials, none gave promising results. An open-hearth steel furnace was operated for three heats on enriched air, but, in view of the slight advantages obtained, the results secured did not justify additional experiments.

About three years ago it was stated that oxygen could be produced in large quantities for $3 a ton. This has not affected the present market price, which is still about $160 a ton. Oxygen at $15 a ton might be considered for certain metallurgical purposes, if such could be secured at this time.

The status of this whole oxygen study is that until some one actually does something, we can theorize all we please. We are not interested in opinions; we are interested in facts.

*Manager, Research Bureau, Carnegie Steel Co., Pittsburgh.

Mr. W. C. Buell, Jr.: All who are giving the subject thought believe that the full-sized installation is the only way to prove or disprove the economic theory involved. Most certainly in such a project it is not for the individual to undertake the consummation of such a project; rather it is for those who would be most benefited. The best the individual should or can do is to foster the interest, in the belief that sooner or later some large organization will recognize the possibilities and be willing to make the initial experimental investment.

Mr. W. H. Brooks:* The work which the United States Bureau of Mines has done on oxygen enrichment, as quoted by Mr. Buell, was realized to be merely a start on a problem which might require years to solve. We would like to spend money to do exactly the thing which Dr. Unger has suggested—to conduct tests under practical operating conditions. However, to-day, we have an economy administration in Washington and our funds are limited. The only reason why such tests have not been initiated in our experimental blast-furnace is the lack of money to start them. I have not personally been connected with this work in such a way that I could speak for the Bureau, but believe I may say that if the steel manufacturers are sufficiently interested to try out in a practical way this idea which gives promise of such interesting fuels economies, the Government would be willing to meet them half way on co-operative commercial-scale tests.

In reference to the Bureau figures of oxygen costs quoted by Mr. Buell, the estimated cost of maintenance has been included in the figure of $3. I might also say that the people who are charging you $160 a ton for oxygen co-operated in the preparation of those figures. The reason for the wide divergence has been pointed out by Mr. Buell. The conditions under which you demand that oxygen be delivered to you at present are quite different from those specified in the Bureau publication in question. The big portion of the $160 which you are now paying is not for oxygen, but for the things connected with its delivery to you in small quantities. The figure quoted is, we believe, a practicable figure and one in which we believe to the extent of putting it on record—something the Bureau very seldom does. We can not definitely prove it until a commercial-scale demonstration is made, as Dr. Unger says.

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Mr. Buell has gone a step ahead of me in his paper, but is one step behind me in another phase of his study. I have had data on my desk for about six months with the idea of endeavoring to write up a paper similar to that which Mr. Buell has so ably presented to-night. I am glad he anticipated me, for he has done it better than I should have. Mr. Buell's contribution, if I correctly interpret it, is an attempt to give an impetus to an idea which seems to give promise of interesting results.

May I digress a bit to give you an analogy. Within the past two weeks it was my privilege to give a paper in Cleveland on the history of pulverized fuel. In preparing it I found that the first experiments were made in pulverized coal firing in 1818—over one hundred years ago. I traced down, one after another, the attempts over that hundred years. Let us assume for the moment that there were twenty subsidiary technical problems to be correctly solved before the method became a practical success. Engineer after engineer got nineteen of the twenty right and one wrong, and their whole attempt failed. Another came along afterward and got *another* nineteen right and *another* one wrong, and *his* attempt failed. The result was nearly a hundred years of experiment before the method became of practical service; not because the idea was not fundamentally sound, but because of lack of sufficient sustained interest on the part of competent engineers. The present popularity of pulverized fuel seems to indicate that the result obtained would have been worthy of more sustained attention and effort by our predecessors. I think the same sustained effort will be necessary for the eventual practical solution of the problem of oxygen enrichment.

I stated that Mr. Buell was one step behind me in another phase of the study of oxygen enrichment. I am leaving Pittsburgh on February 15 to go to eastern Pennsylvania, where for a private consulting client I am initiating a series of tests on a pulverized-coal furnace using oxygen enrichment. We do not expect to get any results this year or maybe in five years from now, but we are going to start something to find out how far we get. We expect to make a lot of mistakes and experience many difficulties; but, in view of the fact that we know that at the River Rouge plant of the Ford Motor Company, and at the plant of the Tennessee Coal and Iron Company, they are

successfully using pulverized coal with producer-gas enrichment, there seem to be interesting possibilities for oxygen enrichment also.

The question of refractory life is, of course, the problem from which I anticipate most difficulty in my experiments. I have had two men for the last year on a series of co-operative tests with the National Electric Light Association on the use of refractories in boiler furnaces. Other Bureau investigators are now studying the use of refractories in open-hearth furnaces. The refractory problem is a big one to-day. We may never get the final answer to it, but we are doing what we can. Whether or not combustion in an oxygen-enriched furnace will be in the form of a "ball of fire," as pointed out by Mr. Buell, remains to be seen from actual tests. This will obviously have considerable bearing on the solution of the refractory problem.

There is an interesting experiment going on under boiler furnaces at the Sherman Creek plant of the United Electric and Power Company, in New York, which I visited last Thursday. They have created a mixing condition in a furnace there by which they claim to be able to burn about 500,000 B.t.u. per cubic foot of combustion space—a rather astonishing figure when one considers the maximum so far in pulverized-fuel firing has been about 30,000. Within the next week we shall make a temperature survey within that furnace to see whether they are actually creating a "ball of fire" or just what the condition is. They have been using water-cooled walls. I was told by the inventor of this device that he did not have to use water-cooled walls—that he could use brick walls. They are now putting in brick walls, therefore, to see what can be done. If they can create the "ball of fire" by their method of firing, I can not see any insurmountable refractory difficulty militating against the use of oxygen enrichment. In so far as the matter of stratification is concerned, it is indeed a difficult problem. But stratification can be and is being broken up, and uniform mixing of gases can be and is being maintained on certain types of furnaces. It is merely a mechanical problem to accomplish that. The answer has been found in certain methods of firing in the past, and I think it could be found in the use of oxygen enrichment.

MR. CHARLES S. PALMER:* I believe it was Sir John Lubbock, the eminent Scotch naturalist, who said, when he was an elderly man,

*Consulting Chemical Engineer, Pittsburgh.

that if he knew that he had still 20 years to live, and if it were possible to give 10 of that 20 years for something, he would give 10 years of life to be able to read the elementary scientific text-books of the next 50 years. So do we feel as we contemplate the possibilities suggested by this paper of Mr. Buell's.

I am sure that we all appreciate the necessarily conservative position of the veteran specialist from the Carnegie Steel Company; but, on the other hand, I would commend the magnificent optimism of Mr. Buell, and of Mr. Brooks, of the United States Bureau of Mines.

This paper will merit careful study; and I am inclined to agree with most of the deductions, as we all know that both "lean" gases, and "rich" gases when burned in the air, with only about 20 per cent. of oxygen, and with about 80 per cent. of nitrogen, both give about the same B.t.u. per cubic foot of products of combustion. The figures are not identical, but about of the same order.

The tables of the paper give theoretical results for 25, 50, 75, and 100 per cent. enrichment of oxygen. That is, 25, 30, 35, and 40 per cent. of actual oxygen in the enriched air. I would like to ask whether Mr. Buell, in planning a trial furnace, would not prefer to start with a relatively small enrichment, such as 25 or 30 per cent. of actual oxygen, rather than with higher amounts, which would presumably give more heat than could well be handled safely.

Mr. W. C. Buell, Jr.: From what we know of furnace design to-day I personally would feel perfectly safe and qualified to design on the basis of 100 per cent. While I lack oxygen experience, I have had a very large experience with highly preheated air. I have handled air up to 2300 and 2500 degrees; and, at these figures, flame-temperature conditions approximate that with 100 per cent. enrichment.

Mr. Charles S. Palmer: There are two main points that come out prominently from this paper, and from private conferences with Mr. Buell and Mr. Brooks, and these are:

1. The chemical side in the cost of production of oxygen. I am rather inclined to think, from the figures of Dr. Unger, if I understood him correctly, that the cost of delivering mere air to the furnaces at 18 pounds (this costs about four cents per thousand cubic feet), and from comparison with the 12 cents for pure oxygen per

thousand cubic feet, that the $3 figure of the United States Bureau of Mines report on this subject is altogether too low. It still remains for the chemist to deliver oxygen at low cost.

2. The other point is that there are wonderful possibilities in the art of so modifying the form and structure of furnaces that most obstacles in the use of enriched air will submit to the experiments of the future. The mechanical engineer will deliver the furnace when the chemist delivers the oxygen. The general outlook is very encouraging.

As to the special method to be used in making cheap oxygen, that is too large a subject to be undertaken here. The final outcome may show a combination of several methods and factors working together in ways not yet dreamed of. And so the mere burning of "fuel" for furnaces still remains the fundamental question in this vast scheme.

Mr. E. J. Stephany:* Mr. Buell, is your figure of 966 B.t.u. per cubic foot intended to represent the gross or the net heating value of Pittsburgh natural gas? A calorimeter test of the natural gas with a composition as shown in your paper will run well over 1100 B.t.u., and the calculated net heating value will be around 1030. Your figure of 966 is altogether too low.

Mr. W. C. Buell, Jr.: The figure of 966 B.t.u. which I have used is the available heating value of one cubic foot. If the analysis given in my paper were calculated on the high-value basis—that is, with the hydrogen at 61,000 B.t.u. per pound, and on the values of C, H and N—then the calorific value would show 1204 B.t.u. If calculated on the low-value basis—that is, with the hydrogen 52,000 B.t.u. per pound—then the value would be 1109 B.t.u.

In the foregoing, no allowance is made for the heat of molocular decomposition, which is 10.2 per cent. for methane and 7.6 per cent. for ethane. If this allowance is calculated and deducted, then the available low heating value will be found at 966 B.t.u.

Mr. E. J. Stephany: Is 966 your calculated result or a test figure?

Mr. W. C. Buell, Jr.: It is a calculated figure.

*Superintendent Sales Department, Equitable Gas Co., Pittsburgh.

MR. E. J. STEPHANY: The calorimeter test of Pittsburgh natural gas will show more than 1100 B.t.u. per cubic foot and I want to make sure that no wrong impressions are given. You stated that with natural gas at 30 cents you get about an even break between the cost of oxygen and the cost of the gas saved. In other words, your cost of the available heat units due to the added oxygen is about the same as the cost of the heat units in natural gas at 30 cents. Are we to understand that you would also have an even break with higher-priced natural gas, say at 40 cents per thousand? The point I wished to have brought out is that oxygen would be of more value when compared with a higher-priced natural gas.

MR. W. C. BUELL, JR.: If the fuel cost increases and the oxygen cost remains the same, the fuel savings percentage increase will go up.

MR. G. M. COMSTOCK:* Referring to the question of cheap oxygen, I understand that Mr. Jeffries and Mr. Morton, of the Morgan Construction Company, Worcester, Mass., have invented and are erecting a commercial plant to manufacture cheap oxygen for another plant designed for the complete gasification of coal. If combustion can be controlled by oxygen or oxygen-enriched air to the advantage of metallurgical furnaces and purposes, it is quite certain that the production of cheap oxygen will be accomplished.

MR. W. C. BUELL, JR.: In closing the paper, the writer wishes to take the occasion to thank the gentlemen who have participated in the discussion, for their efforts have served to emphasize the interest and importance of the subject and to enhance the value of the presentation. If the writer has been able to interest a few more engineers in the general scheme, then the purpose of and the reason for the paper have been accomplished. It has been the effort of the writer to present the subject matter in its simplest form so that the busy engineer will not have to convert a mass of metric values.

The subject is of great interest to users of fuels in industrial plants, and the savings in heating costs indicated by the study give rise to the possibility of the reduction of fuel costs through the method.

*Engineer, Surface Combustion Co., Pittsburgh.

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the Wm. Penn Hotel, Tuesday, April 21st, at 4:45 P. M., President Walter B. Spellmire presiding, Messrs. Fohl, Ellis, Goodspeed, Weldin, Clark, Rankin, Affelder, Clifford and the Secretary being present.

The Minutes of the last regular meeting held March 17th, were approved without reading.

Applications for membership from the following gentlemen, having been published to the Society pursuant to the action of the Board, were elected to membership.

MEMBERS

Bryan, Joseph	Irons, Dean M.
Chaney, George Scott	Johnston, Harold L.
Cott, Parker	Malady, John A.
Drylie, William A.	Riddle, William M.
Hamilton, William Bovard	Wales, Samuel Sigourney

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Smith, Frank B. (A.S.C.E.)	Wilcox, William Ellis

ASSOCIATES

Horelick, Samuel (A.I.E.E.)

JUNIORS

Little, A. R. (A.I.M.& M.E.)	Settle, Samuel Brittan

Applications for membership were received from the following gentlemen and their names ordered published to the Society. Assignment to the various grades of membership was made.

MEMBERS

Borg, John Edward	Lynn, Frederick Edward
Chartener, Victor, Jr.	Sherratt, Gayle F.
Dorsey, Charles H.	Williams, J. P., Jr. (A.I.M.& M.E.)

Wyrough, Clement J.

ASSOCIATE MEMBERS

Bernstein, Lester (A.S.C.E.)	Middleton, Raymond T. (A.S.C.E.)
Eckels, Samuel (A.S.C.E.)	Barrett, Cecil Hewins

Haertlein, Albert

Applications for transfer were received from the following gentlemen and the Secretary was requested to advise them of their transfer to the grade of Member.

Allderdice, Norman	Glass, Roy Charles
Allison, John H.	Klingelhofer, Edward Kohn

Application for reinstatement was received from Mr. T. C. Hughes and the Secretary was requested to advise that his name was again placed on the Society rolls.

Letters of resignation were received from the following members and after discussion, they were ordered accepted.

C. B. Ashmead	H. D. Hukill
J. S. McDowell	C. L. Kline
C. C. Goodrich	F. Schaefer

The Secretary reported the death of the following members:

W. L. Curry, joined May, 1901; died March 22, 1925.
R. C. Crawford, joined June, 1918; died December 26, 1924.
R. R. Hice, joined July, 1910; died March 27, 1925.

On motion the meeting adjourned at 5:15 P. M.

K. F. Treschow, *Secretary.*

MECHANICAL SECTION

The regular bi-monthly meeting of the Mechanical Section was held jointly with the Pittsburgh Section of the American Society of Mechanical Engineers, in the Blue Room, Wm. Penn Hotel, Tuesday, April 7th at 8:13 P. M., Mr. H. C. Cronemeyer presiding in the absence of the Chairman and Vice Chairman, 80 members and visitors being present.

The Minutes of the last meeting held Dec. 2nd were read and approved.

There being no further business, the paper of the evening was presented by J. E. Goodwillie, Engineer, Ingersoll-Rand Company, New York City, N. Y. on Surface Condensers.

On motion duly seconded and carried a vote of thanks was extended to Mr. Goodwillie for his very excellent paper.

The meeting adjourned at 10:03 P. M.

K. F. Treschow, *Secretary.*

REGULAR MONTHLY MEETING

The 430th regular monthly meeting of the Engineers' Society of Western Pennsylvania was held in the Blue Room, Wm. Penn Hotel, Tuesday, April 21st at 8:12 P. M., President Walter B. Spellmire presiding, 130 members and visitors being present.

The Minutes of the last regular meeting held March 16th, were read and approved.

The Board of Direction reported the election of ten applicants to the grade of Member; two to the grade of Associate Member; one to the grade of Associate and two to the grade of Junior and the receipt of twelve applications for membership. There were four transfers to higher grade; one reinstatement; six resignations accepted and three deaths reported.

No further business coming before the Society, the paper of the evening on "What Highway Investigations Have Shown" was presented by Mr. A. T. Goldbeck, Chief, Division of Tests, Bureau of Public Roads, U. S. Department of Agriculture, Washington, D. C.

The ensuing discussion was participated in by: Walter B. Spellmire, Mgr, General Electric Co.; C. M. Reppert, Assistant Director, Dept. of Public Works, Allegheny County; Louis P. Blum, Blum Weldin Co.; A. E.

Anderson, Attorney, Pittsburgh, Pa.; Fred C. Schatz, Asst. Mgr, Jos Horne Company; N. F. Hopkins, Harrop & Hopkins; W. A. Weldin, Blum Weldin Co.; P. J. Freeman, Chf, Engr, Tests & Specifications, Allegheny County; S. W. Jackson, Div. Mgr, State Highway Department, Harrisburg, Pa.; J. P. Leaf, City Engr & Cons. Engr, Rochester, Pa.; Winters Haydock, Chf. Engr, Citizens' Committee on City Plan of Pittsburgh; John A. Ferguson, Cons. Engr, Pittsburgh, Pa.; C. H. Lovejoy, Highway Engr, Pittsburgh Testing Laboratory; and the author.

On motion duly seconded and carried, a vote of thanks was extended to the author for his very interesting paper.

On motion the meeting adjourned at 10:25 P. M.

K. F. Treschow, *Secretary.*

MINING SECTION

The regular bi-monthly meeting of the Mining Section of the Engineers' Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Tuesday, April 28th, at 8:15 P. M., Chairman N. G. Alford presiding, 75 members and visitors being present.

The minutes of the last meeting held Feb. 24th were read and approved.

No further business coming before the Section, the paper of the evening on Mechanical Coal Loading was presented by Mr. Norton C. Newdick President, The Coloder Company, Inc., Columbus, O.

The ensuing discussion was participated in by: W. L. Affelder, Asst. to Pres, Hillman Coal & Coke Co. & Subsidiaries; N. G. Alford, Mining Engr, Howard N. Eavenson & Associates; M. C. Angloch, V. P. Vesta Coal Company; Graham Bright, Cons. Engr, Howard N. Eavenson & Associates; A. P. Cameron, Gen. Mgr, Westmoreland Coal Co, Irwin, Pa.; M. D. Cooper, Asst. Gen. Supt, Hillman Coal & Coke Co. & Subsidiaries; F. B. Dunbar, Gen. Supt, Hillman Coal & Coke Co. & Subsidiaries; H. N. Eavenson, Cons. Engr, Howard N. Eavenson & Associates; H. M. Ernst, Engr, Pittsburgh Terminal Coal Corp.; T. G. Fear, Gen. Supt, Inland Collieries Co, Indianola, Pa.; J. K. Johnston, Pres, Ridgeview Coal Co, Bolivar, Pa.; Julian Kennedy, Consulting Engineer; B. H. Kersting, Mech. Engr, Dravo Contracting Co.; C. E. Lesher, Asst. to Pres, Pittsburgh Coal Company; C. M. Lingle, Mgr, Buckeye Coal Co, Nemacolin, Green Co., Pa.; W. W. MacFarren, Mechanical Engineer; Frank Pardoe, Supt, Lincoln Gas Coal Co, Washington, Pa.; J. W. Paul, Mining Engr, U. S. Bureau of Mines; J. M. Rayburn, Civil & Mining Engineer, Pittsburgh, Pa.; P. A. Young, Mech. Engr, Duquesne Light Co.; and the author.

On motion a vote of thanks was extended to Mr. Newdick for his very interesting paper.

On motion the meeting adjourned at 10:16 P. M.

K. F. Treschow, *Secretary.*

Vol. 41 JUNE 1925 No. 5

PROCEEDINGS

OF THE

ENGINEERS' SOCIETY OF WESTERN PENNSYLVANIA

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WHAT HIGHWAY INVESTIGATIONS HAVE SHOWN*

By A. T. Goldbeck†

You, as engineers, need hardly be informed of the necessity for conducting researches in connection with the construction of road projects which, in the aggregate, total over one billion dollars annually. Your training enables you to sense immediately that careful study of the problems involved in so huge an undertaking must inevitably lead to large economies. Those who have stopped to consider the matter realize that our highway transportation system is made up of thousands of miles of pavements not greatly different in design and of millions of vehicles involving identical principles of operation. It is composed of units in the construction and operation of which are involved mistakes, extravagances or economies all multiplied tremendously.

It must be quite evident why the Bureau of Public Roads and a number of the highway departments are so vitally concerned in looking into the underlying principles involved in proper highway design, construction and maintenance, and into matters having to do with the economics and financing of highways.

Highway investigations extend over a wide field and it would be hopeless for me to attempt to cover this field in a very short time, even though I were capable. It is my purpose, therefore, to confine myself to those phases of highway investigations with which I have been more directly in contact—investigations having to do with the structural design of pavements to meet the present-day traffic needs.

A pavement, as a structure, includes not only the surfacing material but the underlying subgrade as well, and in our investigations we early saw the advisability of making subgrade studies.

In brief, the main questions which seem to require an answer are:

1. What are the distinguishing characteristics of soils which render them stable or unstable in road subgrades?
2. How must the road design be altered to take into account the influence of the subgrade?

*Presented April 21, 1925. Received for publication June 19, 1925.
†Chief, Division of Tests, U. S. Bureau of Public Roads, Washington, D. C.

3. Is it possible to treat the subgrade in any way to eliminate the trouble which the untreated subgrade is likely to produce in the finished road?

We have obtained some very strong indications in answer to these questions, and in the following discussion I wish to present briefly the significant facts developed in our subgrade experiments.

SUBGRADE CHARACTERISTICS

There can no longer be any doubt in the minds of highway engineers that soils do vary considerably in their physical behavior. When the wide variety of geological conditions under which soils have been formed on the surface of the earth is considered, it is easy to understand why they differ so radically. Soils in general are the result of disintegration and weathering of surface-rock formations, varying through the varieties of sedimentary, metamorphic, and igneous rocks with widely differing physical and chemical structures. Other soils have been water borne and deposited; still others have accumulated through the conveying action of strong winds. Throughout the United States we have every variety of soil from the highly plastic clays to solid rock.

One of the first steps in studying subgrades was to develop suitable tests whereby soils having similar characteristics might be recognized in the laboratory through their similarity of behavior when subjected to tests. You are not particularly interested in the details of the laboratory manipulation in conducting the required tests on soils, but you should be familiar in a general way with the kind of tests which we have found to be particularly indicative of the significant characteristic of soils occurring in road subgrades. These tests are listed as follows:

1. Mechanical analysis.
2. Percentage of capillary moisture.
3. Moisture equivalent.
4. Dye adsorption.
5. Slaking value.
6. Moisture capacity.
7. Comparative bearing value.
8. Shrinkage value.

Mechanical Analysis. This consists of determining the percentage of the particles of various sizes, a sample being roughly divided into clay, silt, and sand. Soils which have a high percentage of clay, over approximately 30 per cent., are generally of a very undesirable character requiring special precautions in the pavement design. Such soils are apt to be very plastic when wet, and therefore have very little bearing value. They are apt to swell considerably upon taking up moisture and shrink upon drying out, and therefore offer non-uniform support for the road surface; moreover, because of the large amounts of water which they are able to hold, they are dangerous owing to excessive heaving in times of cold weather. On the other hand, it is quite characteristic that the higher the percentage of coarse particles, such as sand, the less do the above undesirable characteristics appear, and the better are the results to be expected from the sandy or granular types of subgrade.

Percentage of Capillary Moisture. The amount of water which soils are capable of absorbing through their capillary action is important, for ordinarily the road surfacing is not built up to any great extent above the water-table, and, moreover, the pavement itself serves as a preventive against evaporation. Thus, in time, the soil takes up considerable moisture by capillarity from the underlying layers, and this becomes a potential source of harm. Soils having low capillary moisture content are desirable soils for subgrades.

Moisture Equivalent. A test which has been developed by agricultural physicists is the so-called "moisture equivalent" test. In this test, the soil sample is first saturated with moisture and is then placed in a centrifuge and whirled so rapidly that a force is developed on the sample equal to 1000 times its weight. This high centrifugal force acting on the contained moisture tends to draw it away from the sample through the orifices in the container. Considerable moisture remains notwithstanding this high centrifugal force, and the percentage of moisture retained in the sample after a period of one hour of this treatment is known as the "moisture equivalent." Apparently this test is quite indicative of the probable behavior of a soil when used as a road subgrade, and if there is any one test which is more indicative than the others perhaps the "moisture equivalent" test is most important. The values from this test range from a very low percentage for sandy materials up to perhaps 50 or more per cent. for very plastic

clays. There seems to be a good reason for believing, tentatively at least, that it is not particularly safe to build pavements on soils having a "moisture equivalent" higher than approximately 20 without giving serious consideration to the necessity for taking special precautions in the pavement design. It is interesting to note in this connection that it is quite possible to determine the "moisture equivalent" value of soils by means of a simple field test with no elaborate equipment.

Dye Adsorption. When aniline-dye solution is filtered through finly divided soils, the color of the dye disappears upon passing through the soil. A given amount of soil can decolorize only a given volume of dye, and some soils possess this property more than others. Apparently the soil which can decolorize the largest volume of dye is apt to be the soil which is the most plastic and which is most undesirable for subgrades. It often happens that the clay content in two soils is the same, but the clay portion has different characteristics, one clay being capable of decolorizing a far larger amount of dye than the other. Because of these different characteristics of the clay portions, the soils themselves behave in a radically different manner. A high adsorption value is indicative of a poor subgrade material.

Slaking Value. The slaking test consists merely of determining the rate at which a soil will be disintegrated upon immersion in water. Soils vary greatly in this respect, some of them being almost impermeable, requiring a very long time to break up in water, others breaking apart immediately. The significance of the slaking value test is subject to further study, but apparently it has something to do with the rapidity with which the subgrade might be affected by moisture, and also with the rapidity with which drying out might occur after saturation.

Moisture Capacity. The moisture capacity of the soil is determined by saturating the soil, allowing it to drain by gravity, and determining the amount of moisture which remains. This value, no doubt, is tied in closely with the "moisture equivalent" and to some extent with the capillary moisture. Any interpretation of the results of the tests thus far made must be deferred until a better correlation is made with field behavior. In general, however, it might be said that the higher the moisture capacity of the soil, the less desirable is that soil for road subgrades.

Comparative Bearing Value. Since the subgrade supports the road, it would seem that the ability of a subgrade to support loads without yielding should be an important characteristic. In the laboratory, a test for comparative bearing value is made by slowly subjecting the prepared sample of soil to increasing load, and observing the amount of penetration of the bearing area into the soil. Some soils yield under comparatively low load; others support high loads with very little yielding. Plastic clays are of the former type and well-cemented granular soils are of the latter. (See Table 1.)

Shrinkage Value. A very significant test of a subgrade soil is its amount of shrinkage upon drying. Everyone has observed the wide-open shrinkage cracks which form on the surface of a very plastic clay after it has been exposed to the sun and wind. Such cracks indicate very high lateral shrinkage and very high accompanying vertical shrinkage. Under conditions which make for high moisture content, a subgrade of this nature expands vertically, and during times of dry weather the moisture evaporates and the soil shrinks. Owing to the more or less air-tight qualities of a concrete pavement it is natural that evaporation should proceed more rapidly at the edges of the pavement. Moisture samples taken from under roads in California have actually shown that less moisture exists at corresponding depths at the sides of the pavement than under the center. Higher vertical shrinkage is therefore to be expected at the sides than at the center, and it is not surprising that there are times when there is a separation of the subgrade from the pavement. As a result of these conditions, long longitudinal cracks have occurred in concrete pavement surfaces, three or four feet from the edge. It is thus seen that the percentage of shrinkage of the soil is a most important factor, and, where a soil has a linear shrinkage value greater than five per cent., a special design of the pavement or a special treatment of the subgrade is very likely needed.

All of the above tests probably are not necessary and, as has been pointed out, several of the tests are more indicative than others. *The important conclusion, however, is that it is now possible to make laboratory tests on soils, and determine those which have similar characteristics and which are likely to behave similarly in the field.*

While considering the matter of tests it will be well to emphasize particularly the two outstanding tests which up to the present time seem to be those which are most indicative of soil characteristics and

TABLE I. RESULTS OF TESTS OBTAINED FROM COMPLETE ANALYSIS OF FIFTY-SEVEN DIFFERENT SUBGRADE SOILS

Soil No.	Mechanical analysis									Adsorption numbers				Percentage moisture obtained by			Percentage volume change obtained when soil is mixed with			Bearing value, lb. per sq. in. when soil is mixed with		Slaking value	Specific gravity	Mechanical ratio	Voids, per cent.	Moisture equivalent index	Capillary moisture index	Adsorption number of soil × capillary moisture index	Soil No.
	Total sand	Sand, per cent. between sieves				Fine material				Dye adsorbed by 1 g. of material, cc.																			
		10-20	20-50	50-100	100-200	Total	Silt	Clay	Suspension clay	Soil	Silt	Clay	Suspension clay	Moisture equivalent test	Vertical capillarity test	Water capacity test	Moisture equivalent moisture	Vertical capillarity moisture	Water capacity moisture	Moisture equivalent moisture	Vertical capillarity moisture								
1...	69.2	17.6	40.8	7.2	3.6	30.8	3.2	26.8	0.8	10.0	1.3	26.6	182.8	12.8	15.0	22.2	0.0	0.0	10.6	16.5	5.0	1	2.62	2.63	29.8	0.79	0.93	9.3	1
3...	38.8	1.6	7.2	15.6	14.4	61.2	26.4	33.2	1.6	15.0	2.5	30.2	89.3	17.6	28.4	38.2	6.4	17.6	23.6	18.9	0.0	20	2.68	1.87	35.3	0.87	1.41	21.2	3
4...	52.0	7.2	20.0	11.2	13.6	48.0	20.4	25.6	2.0	35.0	7.5	118.0	111.1	13.5	28.2	34.9	5.1	21.6	27.2	20.+	0.0	3	2.64	2.62	32.9	0.73	1.52	53.2	4
5...	70.4	6.8	34.4	15.2	14.0	29.6	18.0	10.8	0.8	7.5	6.3	53.5	181.8	7.2	20.4	25.3	0.0	10.7	12.6	20.+	0.0	1—	2.71	7.63	31.4	0.43	1.21	9.1	5
6...	41.2	7.6	15.6	8.4	9.6	58.8	26.8	30.0	2.0	22.5	6.3	52.8	141.8	22.8	32.1	44.1	6.5	16.2	25.4	20.+	1.2	16	2.66	2.12	41.5	0.86	1.20	27.0	6
7...	12.8	3.2	4.0	2.4	3.2	87.2	22.8	62.8	1.6	40.0	6.3	56.9	125.5	30.3	37.7	50.3	22.0	26.0	34.2	6.4	1.8	39	2.72	0.55	36.3	1.47	1.83	73.2	7
8...	2.8	0.0	0.8	0.4	1.6	97.2	50.8	43.2	3.2	30.0	3.8	56.4	129.1	23.8	30.3	45.9	13.9	21.5	27.2	3.3	1.7	21	2.69	1.16	42.5	0.87	1.11	33.3	8
9...	4.4	0.4	1.6	1.2	1.2	95.6	51.6	41.6	2.4	22.5	2.5	44.5	73.5	20.4	28.6	36.9	0.0	14.6	23.6	17.4	1.8	15	2.67	1.27	35.1	1.01	1.41	31.7	9
10...	15.6	0.8	3.2	4.4	7.2	84.4	58.6	23.6	2.2	22.5	3.7	77.1	63.2	22.0	30.8	43.6	0.0	8.5	20.6	20.+	1.7	4	2.67	2.88	41.9	0.82	1.14	25.7	10
11...	31.2	0.4	9.2	11.6	10.0	68.8	46.4	21.2	1.2	8.3	2.5	26.8	66.6	15.8	22.2	29.0	0.0	0.0	11.5	20.+	2.0	2	2.66	3.47	36.5	0.73	1.03	8.5	11
12...	37.6	2.8	16.4	11.2	7.2	62.4	25.6	33.2	3.6	17.5	5.0	38.8	66.5	15.4	26.6	44.3	6.6	19.7	27.7	20.+	1.7	39	2.67	1.72	36.5	0.72	1.23	21.5	12
13...	12.0	2.0	4.0	2.0	4.0	88.0	42.0	44.8	1.2	17.5	5.0	28.5	60.2	23.3	33.1	42.1	5.9	13.0	18.8	20.+	2.0	5	2.68	1.18	42.7	0.84	1.20	21.0	13
14...	26.8	2.8	7.2	7.2	9.6	73.2	24.4	46.0	2.8	55.0	8.8	111.8	138.9	22.2	27.3	47.6	18.0	23.4	33.1	15.7	3.3	300+	2.58	1.05	33.1	1.15	1.42	78.2	14
15...	26.4	5.2	6.0	5.2	10.0	73.6	32.0	38.8	2.8	22.5	10.0	40.6	128.5	25.6	31.8	49.2	18.9	23.2	38.4	2.9	1.3	36	2.64	1.40	34.1	1.31	1.63	36.7	15
16...	34.0	3.6	7.2	4.8	18.4	66.0	27.2	36.4	2.4	80.0	5.0	175.8	128.2	31.7	34.5	62.4	28.0	29.0	40.6	4.5	2.9	59	2.55	1.58	35.1	1.48	1.61	128.8	16
17...	22.4	3.2	4.8	5.2	9.2	77.6	25.6	48.4	3.6	70.0	5.0	115.2	108.7	26.8	28.8	51.2	28.0	28.6	41.4	8.9	6.6	65	2.50	0.92	24.0	2.12	2.28	159.6	17
19...	28.4	2.0	5.2	6.0	15.2	71.6	42.0	26.0	3.6	15.0	2.5	21.8	125.0	15.6	27.7	36.7	7.6	19.2	26.4	13.4	1.1	6	2.62	2.37	31.8	0.88	1.53	23.4	19
20...	9.2	0.8	2.0	2.0	4.4	90.8	15.6	72.0	3.2	130.0	2.5	182.7	92.6	28.8	30.6	56.1	31.6	32.5	45.1	13.9	6.9	5	2.56	0.33	26.5	2.12	2.26	294.0	20
22...	18.0	2.0	6.0	4.0	6.0	82.0	25.2	53.6	3.2	90.0	7.5	148.9	166.6	23.4	25.1	46.6	28.6	30.0	40.7	19.5	11.7	6	2.62	0.76	27.6	1.61	1.72	154.9	22
23...	47.2	5.2	16.4	12.8	12.8	52.8	12.0	37.6	3.2	57.5	6.3	113.6	107.1	17.7	27.8	51.5	12.4	23.1	32.2	20.+	13.5	7	2.54	1.45	35.9	0.79	1.26	72.4	23
24...	22.4	0.8	2.4	8.8	10.4	77.6	24.8	49.2	3.6	90.0	10.0	142.8	83.3	27.0	41.1	61.7	29.2	39.0	44.8	20.+	2.3	2	2.63	0.90	34.7	1.34	2.03	182.7	24
25...	28.4	4.0	8.0	8.8	7.6	71.6	25.9	41.6	4.1	150.0	12.5	371.0	216.0	35.8	47.0	67.8	36.6	40.2	47.0	9.9	0.9	2	2.42	1.19	29.2	2.10	2.76	414.0	25
26...	15.2	2.0	3.6	4.0	5.6	84.8	24.4	56.0	4.4	154.8	7.5	256.0	160.7	39.5	43.1	67.2	40.9	40.7	42.3	3.9	3.5	2	2.53	0.66	43.9	1.27	1.39	215.2	26
27...	20.8	2.8	6.0	4.8	7.2	79.2	27.2	48.8	3.2	127.5	7.5	261.1	111.8	41.4	57.3	69.2	36.2	39.7	42.4	3.1	0.0	1	2.55	0.92	39.6	1.61	2.24	285.2	27
28...	22.0	0.4	6.0	5.6	10.0	78.0	44.0	30.4	3.6	45.0	6.3	37.7	57.5	19.2	42.4	45.4	5.6	22.6	24.0	14.9	0.0	7	2.70	1.94	40.4	0.76	1.69	76.1	28
29...	66.0	0.4	30.8	22.4	12.4	34.0	4.7	26.3	3.0	25.0	6.3	86.9	93.9	6.3	17.7	29.9	0.0	10.0	17.2	20.+	2.2	4	2.70	2.41	31.9	0.36	1.02	25.5	29
30...	84.0	7.2	43.6	22.4	10.8	16.0	6.0	8.8	1.2	5.0	1.3	32.3	54.3	2.0	18.8	22.7	0.0	0.0	6.0	20.+	0.0		2.69	9.00	31.1	0.12	1.12	5.6	30
31...	13.2	0.4	1.2	2.8	8.8	86.8	23.2	60.4	3.2	100.0	7.5	241.0	58.1	24.6	33.1	47.1	26.9	33.2	41.8	20.+	2.9	4	2.66	0.58	27.4	1.74	2.34	234.0	31
32...	53.6	3.2	20.4	17.6	12.4	46.4	13.2	31.6	1.6	42.5	7.5	77.3	90.9	17.4	23.0	34.8	8.4	14.4	23.0	14.2	1.7	8	2.67	2.01	31.4	1.01	1.34	56.9	32
33...	3.6	0.4	1.2	0.8	1.2	96.4	29.5	64.2	2.7	90.0	22.5	129.4	159.4	34.0	35.2	61.6	20.0	20.0	43.2	7.9	7.3	18	2.65	0.50	37.8	1.48	1.53	137.7	33

TABLE I. *Continued*

Soil No.	Mechanical analysis: Sand, per cent, between sieves: Total sand	Sand 10-20	Sand 20-50	Sand 50-100	Sand 100-200	Fine material: Total	Fine material: Silt	Fine material: Clay	Fine material: Suspension clay	Adsorption numbers: Dye adsorbed by 1 g. of material, cc.: Soil	Dye: Silt	Dye: Clay	Dye: Suspension clay	Percentage moisture obtained by: Moisture equivalent test	Vertical capillarity test	Water capacity test	Percentage volume change obtained when soil is mixed with: Moisture equivalent moisture	Vertical capillarity moisture	Water capacity moisture	Bearing value, lb. per sq. in. when soil is mixed with: Moisture equivalent moisture	Vertical capillarity moisture	Slaking value	Specific gravity	Mechanical ratio	Voids, per cent.	Moisture equivalent index	Capillary moisture index	Adsorption number of soil × capillary moisture index	Soil No.
34..	45.6	2.0	7.6	16.0	20.0	54.4	21.2	30.8	2.4	33.8	8.8	51.1	75.8	19.4	24.8	36.6	7.1	16.7	24.4	20.+	4.5	..	2.63	2.04	36.6	0.88	1.13	38.2	34
36...	41.6	2.4	8.8	13.6	16.8	58.4	22.0	34.4	2.0	31.3	12.5	75.0	125.0	20.2	34.3	39.3	6.7	19.7	23.6	20.+	1.0	11	2.57	1.76	34.7	0.98	1.66	52.0	36
37..	23.2	2.0	11.2	6.8	3.2	76.8	39.2	34.4	3.2	55.0	17.5	66.2	64.8	26.1	35.2	55.4	11.3	20.0	31.0	20.+	16.0	300+	2.43	1.66	38.0	1.03	1.39	76.4	37
38...	90.4	1.6	20.4	44.4	24.0	9.6	2.8	5.6	1.2	7.5	2.5	77.3	55.0	3.5	22.2	24.6	0.0	0.0	7.8	20.+	6.4	1—	2.64	13.70	35.5	0.17	1.06	8.0	38
42..	8.4	0.4	0.8	1.2	6.0	91.6	9.6	70.8	11.2	120.0	2.5	141.0	113.0	40.7	46.8	49.8	36.2	36.5	38.4	20.+	20.+	5	2.73	0.22	37.8	1.83	2.11	253.2	42
44..	18.0	4.0	6.4	2.4	5.2	82.0	10.4	68.4	3.2	140.0	7.5	229.3	190.5	27.6	30.6	63.0	26.4	29.6	39.6	20.+	14.3	5	2.65	0.39	39.1	1.14	1.26	176.5	44
50...	17.6	1.2	4.8	4.8	6.8	82.4	43.6	36.0	2.8	38.8	20.0	82.0	97.1	23.4	35.7	54.9	14.6	23.4	30.2	20.+	1.6	300+	2.58	1.57	40.7	0.88	1.34	52.0	50
51..	38.0	3.2	12.8	11.2	10.8	62.0	19.0	39.6	3.4	52.5	7.5	114.9	62.5	22.2	27.4	50.1	16.4	18.0	32.2	8.4	2.3	6	2.69	1.32	36.5	1.04	1.29	67.8	51
55..	14.4	1.6	6.0	3.6	3.2	85.6	49.6	33.6	2.4	55.0	7.5	148.0	121.0	24.7	26.6	47.2	17.4	20.0	31.4	5.6	2.6	21	2.63	1.77	36.1	1.15	1.24	68.2	55
56..	6.0	0.8	2.4	1.2	1.6	94.0	66.0	24.0	4.0	18.8	11.3	53.0	44.6	21.4	33.3	47.2	0.0	0.0	23.0	20.+	0.9	2	2.61	2.57	43.9	0.71	1.11	20.9	56
59...	8.8	0.0	3.2	4.0	1.6	91.2	56.4	31.6	3.2	40.0	8.8	95.9	65.8	22.9	29.9	54.8	17.5	21.6	34.6	10.0	2.1	8	2.67	1.87	38.3	0.99	1.29	51.6	59
80...	31.6	2.8	8.0	7.6	13.2	68.4	26.6	39.2	2.6	22.5	3.8	43.9	81.1	19.2	25.8	40.9	12.2	18.0	33.8	7.3	1.4	42	2.72	1.39	33.7	1.03	1.38	31.0	80
92..	55.2	1.6	14.4	18.8	20.4	44.8	12.8	30.0	2.0	35.0	5.0	38.6	214.3	19.2	31.3	42.0	5.8	19.5	26.3	20.+	1.1	4	2.61	2.13	42.7	0.67	1.10	38.5	92
119..	14.4	0.8	2.8	4.0	6.8	85.6	40.0	43.6	2.0	20.0	5.0	23.0	154.0	21.1	32.5	43.1	5.2	18.8	27.0	18.2	0.8	5	2.65	1.19	39.9	0.84	1.30	26.0	119
120..	1.6	0.0	0.4	0.4	0.8	98.4	22.0	73.6	2.8	50.0	22.5	82.5	93.4	37.3	40.9	65.8	28.0	30.9	46.4	20.+	14.1	10	2.73	0.31	34.7	1.91	2.09	104.5	120
157..	35.6	2.4	7.2	10.0	16.0	64.4	18.8	41.2	4.4	110.0	7.5	103.7	99.0	24.8	31.3	57.5	27.4	31.8	49.6	20.+	15.7	6	2.65	1.19	21.2	2.44	3.08	338.8	157
158..	94.0	9.2	45.6	28.0	11.2	6.0	0.8	4.0	1.2	2.5	5.0	35.7	80.6	2.2	17.4	23.3	0.0	0.0	0.0	20.+	20.+	1—	2.73	18.30	43.6	0.08	0.62	1.6	158
186..	43.6	2.4	7.6	12.8	20.8	56.4	21.4	31.6	3.4	35.0	7.5	90.4	103.0	17.3	30.6	41.7	6.0	26.7	32.3	20.+	0.0	24	2.64	1.85	35.9	0.82	1.45	50.8	186
188..	78.4	22.4	30.8	14.8	10.4	21.6	6.7	13.4	1.5	15.0	2.5	85.1	90.9	6.1	18.7	26.1	0.0	0.0	13.0	20.+	1.2	1	2.63	5.71	28.7	0.40	1.22	18.2	188
200..	26.8	1.6	4.4	4.8	16.0	73.2	32.8	36.4	4.0	57.5	5.0	140.6	107.1	20.0	31.0	46.9	11.7	24.6	30.3	16.5	1.7	17	2.70	1.47	35.1	1.00	1.55	89.2	200
201..	70.8	15.2	28.8	15.2	11.6	29.2	8.8	18.8	1.6	15.0	3.8	61.0	101.6	9.6	23.6	32.7	0.0	0.0	19.8	20.+	1.0	11	2.70	3.91	33.0	0.53	1.29	19.4	201
202..	70.0	8.8	27.6	18.8	14.8	30.0	12.0	16.0	2.0	25.0	5.0	115.6	130.7	8.2	13.8	30.3	0.0	0.0	17.7	20.+	9.2	3	2.63	4.56	30.8	0.47	0.82	20.5	202
290..	74.4	8.0	29.6	22.8	14.0	25.6	9.6	14.4	1.6	6.3	2.5	30.0	91.0	6.8	19.3	29.0	0.0	14.0	15.0	20.+	0.2	17	2.64	5.25	31.4	0.39	1.11	7.0	290
291..	65.6	6.8	23.2	20.0	15.6	34.4	15.2	17.6	1.6	7.5	2.5	40.2	136.5	9.4	21.0	30.9	0.0	6.0	16.4	20.+	3.5	33	2.61	4.21	34.9	0.46	1.02	7.7	291
292..	30.0	1.3	9.4	11.6	7.7	70.0	6.9	61.0	2.1	32.5	10.0	50.4	89.2	28.9	51.4	70.2	8.8	22.0	29.4	20.+	20.+	43	2.64	0.59	52.7	0.68	1.21	39.4	292
293..	74.8	9.6	30.8	21.6	12.8	25.2	10.8	12.0	2.4	7.5	2.5	36.0	69.4	6.6	18.7	30.0	0.0	0.0	17.0	20.+	1.9	6	2.63	5.94	30.4	0.39	1.11	8.3	293
294..	77.6	4.0	30.0	27.2	16.4	22.4	8.8	12.0	1.6	7.5	5.0	36.1	160.0	4.9	19.0	25.7	0.0	0.0	12.2	20.+	3.6	8	2.65	6.35	33.1	0.26	1.02	7.7	294

which at the same time are comparatively simple to make. They are the so-called "linear shrinkage test" and the field test for "moisture equivalent." It has been stated that the "moisture equivalent" of a soil is the percentage of water which remains in a saturated sample of soil after it has been subjected to 1000 times the force of gravity for a period of one hour. It has been found by trial that the "moisture equivalent" condition might be very closely approximated by a field method which, although having no relation whatever to the essential laboratory conditions in making the test, yet for practical purposes gives identical results.

Field Test for "Moisture Equivalent." The test is made by placing a 500-gram sample of air-dried soil in a bowl, breaking up the lumps, adding water slowly from a burette, mixing the water and soil until the mixture reaches the consistency of putty and may be compacted with a spoon or spatula without any free water remaining on the surface. Water is then allowed to drop upon the smoothed surface. If it is rapidly absorbed, "moisture equivalent" percentage has not been reached. More water is then mixed with the sample and a second absorption trial is made as above. Before the "moisture equivalent" percentage is reached, the sample will absorb water readily; but, when the critical value is passed, the surface will retain a wet, shiny appearance. The sample is then dried at 105 degrees C., and the percentage of water is calculated on the basis of the dry weight of the soil. All of this may be performed in the field.

Linear Shrinkage Test. A 300-gram sample of soil, wetted to "moisture equivalent" percentage as previously determined, is packed in ½-inch layers in a galvanized-iron mold. The bars are then pushed from the mold upon a porcelain plate, calipered for length, oven dried, and calipered again. The difference in length computed as a percentage of the wet length of the bar is considered the linear shrinkage percentage.

Both of these tests are simple, and through a comparison of a number of soils with roads of which the behavior has been observed it has become our opinion that if a soil has a linear shrinkage value in excess of five per cent., or, if its "moisture equivalent" value exceeds 20 per cent., such a soil is apt to cause trouble, for ordinarily this type of soil will cause excessive vertical movement of the pavement due either to shrinkage or to freezing of the moisture. Moreover, such a

soil is capable of absorbing large amounts of moisture and will therefore be apt to have very low supporting value during times of wet weather.

It must be recognized that there are so many conditions which determine whether or not a soil will cause trouble, that the above cited figures are not to be considered definite, as they might vary somewhat, depending upon the severity of the conditions. The factors which necessarily make for a sliding scale of division between good and bad soils include traffic intensity, amount of moisture precipitated, degree of humidity, temperature, drainage conditions, topography, and perhaps others. By means of the above tests, however, a bad soil can be recognized and distinguished from a good soil for subgrade purposes.

Investigations on Moisture in the Subgrade. A number of investigations have been made on the question of water in road subgrades. These include laboratory investigations and investigations in the field. It will be impossible to go into the details of all of these investigations, but perhaps it will be sufficient to state the conclusions and their probable significance from the road-building standpoint. In the first place, so far as we have been able to determine, it seems that the moisture in road subgrades might be considered as occurring in three forms:

1. Free water.
2. Capillary moisture.
3. Water vapor.

By "free water" we mean water which will flow through a soil under the action of gravity. By "capillary moisture" is meant the water which is held in the soil by virtue of the capillary action of the minute voids. By "water vapor" we imply the vapor which results from the evaporation of either free or capillary moisture. All of these three forms of moisture are important in their relation to the behavior of road subgrades. No experiments are needed to tell us that excessive moisture is very detrimental, and every effort must be made to reduce the moisture content to a minimum. The following are conclusions which have been arrived at with regard to these varied forms of moisture in the subgrade:

1. When free moisture exists in the soil, drainage systems such as French drains, tile drains, or ditches, as the case may require, should be provided to exclude this water from under the road surface.

2. It seems to be apparent that drainage methods satisfactory for removing free water are of no value for removing capillary moisture.

3. It is apparent that capillary action is accentuated by low temperatures and that excess capillary moisture will be found in the colder layers under the pavement.

4. Soils vary greatly not only in the amount of capillary moisture which they will retain, but in the height to which capillary moisture will rise. This has an important bearing on the height of road-bed above the water-table.

5. Water vapor within the soil is condensed in the cool surface layers, and such condensation might lead to the production of free water immediately under the pavement, and this becomes destructive in freezing weather.

6. All of the water in soils is not available for freezing and, in general, it might be said that those soils showing by laboratory tests the poorest subgrade characteristics are those in which the lowest percentage of total water contained is capable of being frozen, even at very low temperatures. For instance, in clean standard Ottawa sand 100 per cent. of the water will freeze at —1.5 degrees C., whereas, in certain soils it is impossible to freeze any of the water at this temperature. It is apparent that the amount of water which is available for freezing depends upon a number of factors such as the physical, chemical, and mineralogical composition of the soil; the amount of soluble salts; organic matter, and colloidal material. In soils having a high percentage of soluble salts none of the water will freeze at temperatures ordinarily encountered in road subgrades. This suggests the possibility of preventing trouble from freezing by the artificial admixture of salts suitable for this purpose.

7. Pavement vibration under passing traffic has little effect on the moisture content in the subgrade.

A few remarks in amplification of the above conclusions will not be amiss at this time. Most of our measurements indicate that condensation of moisture begins to take place under the pavement after a drop of less than five degrees in temperature, for the relative humidity of the air in the voids of the subgrade material is always so high that the dew-point is never more than a few degrees below the temperature of the air. In view of the fact that the pavement surface greatly

retards evaporation, it is plain that the water which condenses in the top layers of the soil immediately beneath the pavement must soon accumulate and cause a soft subgrade condition. The water vapor which condenses is supplied by capillary moisture in the soil or at times also by free water.

In the summer, because of high air temperature, evaporation takes place quite rapidly from the subgrade and, moreover, the water-table is lower, the rate of capillary action is lower and condensation is reduced. For these reasons, except where free water abounds, the subgrade material is not apt to be wet. On the other hand, in the winter time, condensation is greatly increased, capillary action is likewise hastened, there is a lower rate of evaporation due to low air temperatures, and thus the condensed water accumulates beneath the pavement. As this condensed moisture freezes and is added to by underlying capillary moisture at a greater rate in some spots than in others, the building up of ice under the pavement is accounted for and the local and uneven heaving which takes place is thus explained.

Subgrade Treatment Under Non-Rigid Types of Pavement. It has been pointed out that owing to the combined effects of percolation, capillarity, condensation, and prevention of evaporation by reason of the presence of the pavement surface, moisture accumulates in excessive amounts under the pavement in the spring of the year. In soils having bad characteristics this leads to excessive softening so that the soil is capable of carrying very little load; to excessive shrinkage when the soil dries out; to excessive heaving due to freezing of this large amount of moisture; and, in general, to unstable subgrade conditions.

In connection with the non-rigid type of pavement, such as macadam or gravel, the well known so-called frost boil is a common phenomenon occurring in the spring when the subgrade is soft in particular spots. This is brought about largely by the excessive quantity of water in the subgrade at these locations. Because of its softened condition, the soil is displaced under the heavy loads vertically and horizontally, rupturing the road surface, with the result that the subgrade material is forced upward through the surface break.

No doubt the lack of supporting value of the non-rigid pavement during the spring of the year is contributed to by the fact that the full depth of the surfacing has been rendered ineffective, because under passing loads the soft plastic material is forced up into the voids in the

large-sized material at the bottom of the pavement. Undoubtedly the lower layers are more or less lubricated, or at least rendered much less stable. If the lower voids could be kept filled with granular, stable material instead of with plastic clay, the pavement efficiency would be increased for carrying loads. This leads to the proposition of using a lower course of finely granular material under a macadam base or pavement, with the idea of its serving as a blanket layer to prevent the intrusion of the soft subgrade up into the voids in the stone or into the cracks formed in the surfacing under loads. Such a layer has already been used with considerable success, and the laboratory tests which have been made bear out its efficiency for this purpose. The experiments thus far seem to show that a layer of suitable sand, bank-run gravel, or cinders necessary to prevent the intrusion of clay into the stone was about two inches when 1½-inch stone was used. In no case was there any mixing of the sand or cinders with the clay, and apparently the failures which took place occurred in the form of vertical shear through the stone with the consequent intrusion of the clay. A layer of compacted granular material four inches in thickness should be very valuable in connection with non-rigid pavements laid on a bad subgrade.

Another benefit to be derived from this blanket layer is the decreased unit pressure on the soft underlying subgrade because of the greater thickness of pavement provided. The admixture of sufficient sand with a bad subgrade will accomplish the same results, but the percentage of sand to clay in the mixture must be very large to be of any value. The well known load-supporting value of a sand-clay road furnishes an example of the benefit to be derived from a mixture of this sort. It is not believed that any kind of subgrade treatment can be of value unless the free water is taken care of by thorough drainage. It is, of course, unreasonable to suppose that a thin blanket layer will prevent the general rising of the road due to freezing of the subgrade to any considerable depth; but, if the rising and subsidence are more or less uniform, no particular harm can result from this effect.

Subgrade Treatment for Rigid Types of Pavement. Those who have had long experience in the building of concrete bases and pavements on extremely bad types of soils, which swell and shrink with varying moisture content, state positively that the only method

which has been successful for preventing the excessive cracking of concrete under these conditions is the use of a layer of granular material such as sand rather loosely compacted. The real explanation of the behavior of this layer under these conditions does not seem to have been reached. However, when we consider that this bad type of soil increases in volume a great deal upon the taking up of moisture, it becomes readily apparent that moisture might be absorbed from the concrete the minute it is poured, and the subgrade then swells unequally—more in some spots than in others. While it is still green, the concrete has practically no cross-breaking strength and is incapable of bending. It would seem then that, due to this action, minute cracks must form in the very early stages of hardening, which show up later upon contraction on drying out. The provision of a layer of sand serves merely to prevent the rapid taking up of moisture from the concrete until it has hardened and attained high cross-bending strength. This method has been used very successfully in Los Angeles County, California, where heavy adobe subgrades are encountered. Adobe is at the extreme end of bad soil characteristics.

We have tentatively set up as a dividing line between good and bad soils quantities of five per cent. linear shrinkage and 20 per cent. moisture equivalent, and soils worse than indicated by these quantities will exhibit characteristics of the adobe soil only to a lesser degree. With such soils, it seems desirable to provide a layer of granular materials under a concrete pavement primarily to serve the following purposes:

1. To furnish a layer with characteristics unaffected by moisture.
2. To provide for more uniform pavement support, primarily during periods of localized freezing in the subgrade.
3. To increase to some extent the load-carrying value of the pavement through the increased thickness provided by the blanket layer.
4. To take advantage of the possibility, as indicated by some of our measurements, that the actual moisture content in the underlying subgrade is somewhat reduced thereby.

At the present time no strong assertion can be made of the benefits to be derived from a granular layer under a concrete pave-

ment to take care of excessive cracking due to bad subgrade conditions particularly due to ice action. There are examples, however, where such treatment has certainly proved successful, and there is no question that this treatment is successful for taking care of excessive swelling and shrinking of extremely bad subgrades. The benefit of such a layer under macadam and gravel types does not seem to be open to any question. All of you, however, know that the subgrade is only one part of the pavement structure. Technically, we may get beneficial results by recognizing these differences in subgrades and by providing a subgrade treatment where the soils are bad; but, on the other hand, it may be possible so to alter the surface design that equally good results will be obtained.

After all, the proper procedure is to design the combined structure—the subgrade and the surfacing—to get the best results with the least cost, and that part of the problem is one which must be applied to each individual project.

SURFACING OF CONCRETE PAVEMENTS

So much for the question of the subgrade. We shall next consider investigations having to do primarily with the surfacing, and we shall further limit the discussion largely to concrete pavements. Instead of presenting our research conclusions merely as detached results of separate research projects without relation to one another, I should prefer to present the essential conclusions in a manner which will show their application to concrete pavement design. In order to render the discussion more complete it will be necessary to draw on results and experiences obtained from investigations other than those conducted by the United States Bureau of Public Roads. To give full consideration to the many elements which have influence on the design of a concrete pavement, I think it will be well for us to follow the concrete pavement through from the very beginning and see what are the principal forces which the pavement must withstand and what are the properties of the pavement material which are brought into action in resisting these forces.

Almost from the moment the concrete is deposited on the subgrade it begins to stiffen and harden and immediately it is subjected to forces, the effects of which may or may not be immediately apparent. For instance, we are all familiar with the surface checking which

sometimes results within a very short time after depositing, especially in times of hot weather and high winds. Concrete shrinks upon drying and, in shrinking, cracks are formed at this early stage of hardening, for then the concrete has practically no strength. It is highly important that protective measures, such as the use of a covering of wet burlap, be used to combat this property of concrete of shrinking upon drying. There seems to be some ground for believing also that the subgrade might take up water from the concrete with a resulting local vertical expansion of the subgrade material which exerts upward force in spots, again with a resulting cracking of the concrete. This action is especially prevalent on subgrades having bad characteristics such as previously pointed out and, as stated, the remedy seems to be the provision of a sand layer. Unless immediate measures are taken to keep the concrete moist the moisture will evaporate and shrinkage will occur. Since shrinkage must result in the dragging of the concrete over the subgrade and consequently in the setting up of tensile stresses, it will be seen how necessary it is to keep the concrete moist to prevent this action. Tensile stresses must not be permitted until the concrete has gained sufficient strength to develop resistance to tension. The concrete is therefore kept moist preferably for a period of at least several weeks. It is then allowed to dry out, and immediately it begins to shrink and draw itself over the subgrade. This action necessarily results in the production of tension in the concrete and, when frequent expansion joints are not provided, transverse cracks are unavoidable at this period. The higher the resistance of the concrete to tension the farther apart are these transverse cracks, and it is therefore important to delay the shrinkage of the concrete as long as possible in order that high tensile strength may be attained. In the meantime, as the concrete has been setting, the temperature of the air has been changing almost every hour, and that part of the pavement in contact with the subgrade necessarily remains at a more uniform temperature than the top surface. The top surface therefore has been expanding and contracting owing to thermal effects, while the bottom surface has been remaining relatively stationary. This necessarily results in the bending of the slab, in the setting up of bending stresses due to the dead load of the slab, and in the local effects of the expansion and contraction within the concrete. It might also be the case that a period of high temperature might occur, resulting in an expan-

sion of the concrete and the production of high compressive stress. Finally the pavement is opened to traffic and immediately there are additional stresses of flexure due to the bending action of heavy wheel loads, applied sometimes with static and sometimes with dynamic effect. Traffic also tends to abrade the immediate surface, and it is therefore necessary that it have high resistance to abrasion.

We are now in a position to set down the various properties of concrete which seem to be important for consideration in the design of a concrete pavement. They are:

1. Expansion and contraction due to changes in moisture.
2. Expansion and contraction due to changes in temperature.
3. Tensile resistance.
4. Resistance to bending.
5. Compressive strength.
6. Resistance to repeated stress.
7. Resistance to abrasion.

Expansion and Contraction of Concrete Due to Changes in Moisture. A number of experimenters have studied the action of moisture on the changes in length of concrete, but perhaps more work has been done on neat cements and mortars than on concrete of the proportions used in highway construction. This subject was studied by the Bureau of Public Roads in 1911[1],* and recently has been studied at Purdue University, and I understand also at the University of Michigan.

Curves typical of those obtained by the Bureau of Public Roads are given in Fig. 1. It will be observed that as long as concrete is kept moist it remains expanded, but that as soon as it is subjected to drying-out conditions it begins to shrink, and in this its properties resemble those of timber. The maximum percentage of expansion obtained in the Bureau of Public Roads tests amounted to 0.0001 inch per inch of length, and upon complete drying out the shrinkage was approximately 0.0005 to 0.0006 of an inch. The amount of shrinkage depends to a considerable extent on the characteristics of the cement used and also on the degree of drying to which the specimen has been subjected. The more complete the drying, the greater the percentage of shrinkage. It is not to be expected that road concrete will shrink

*See references at end of paper.

to the same extent as laboratory concrete, because the underside of the slab is invariably at least damp, whereas a laboratory specimen may become quite dry. When a specimen which has been dry is again subjected to moisture conditions it expands, but the rate of expansion is very slow, as seen from the curves in Fig. 1. The presence of reinforcing steel reduces the shrinkage of concrete due to the evaporation of moisture, as also illustrated in Fig. 1.

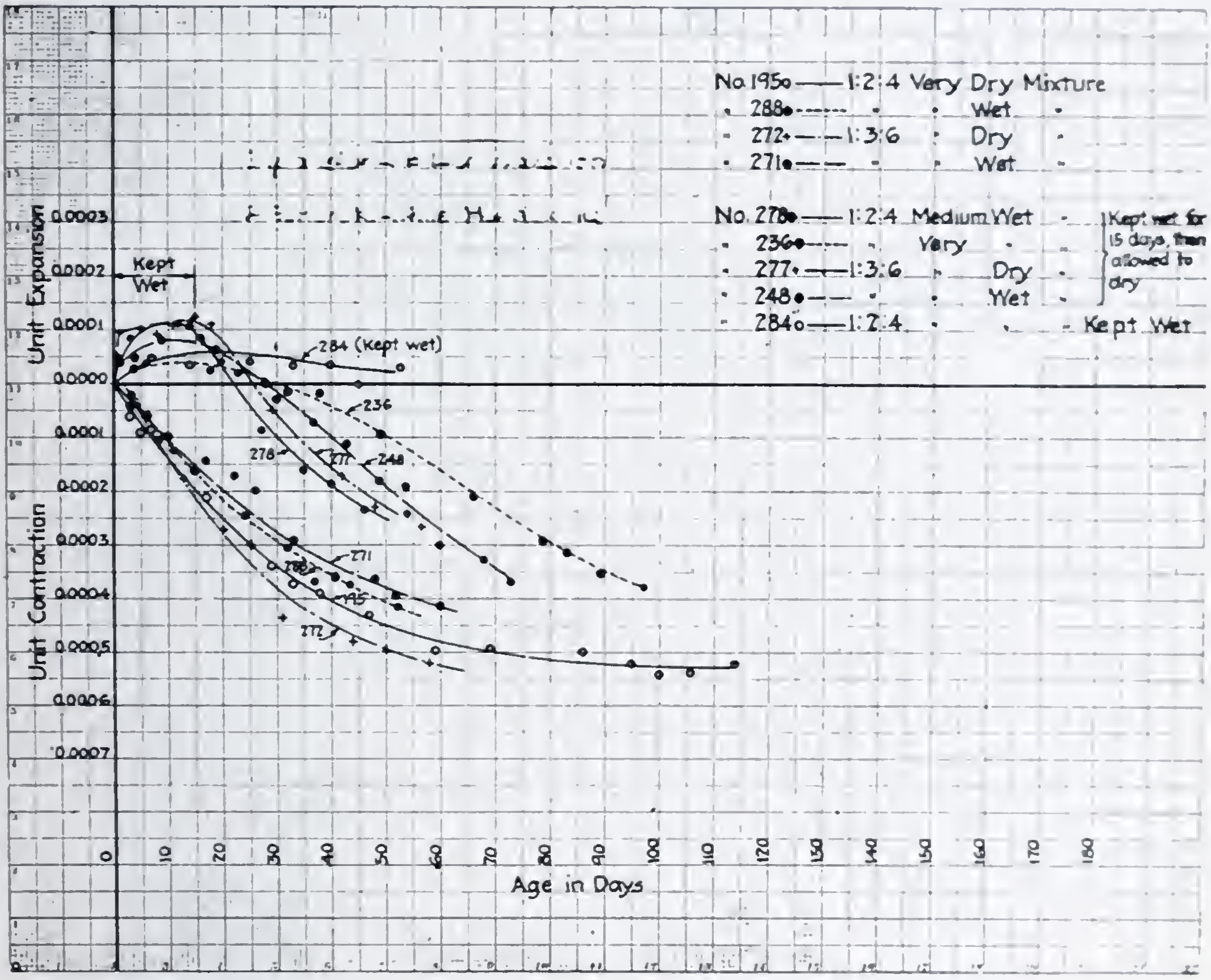


Fig. 1. Expansion and Contraction of 1:2:4 and 1:3:6 Concrete Alternately Wet and Dry.

Temperature Expansion of Concrete. We have been accustomed to accept a figure for the coefficient of expansion of concrete of approximately 0.0000055. Recent experiments, however, conducted at Purdue University under the direction of W. K. Hatt, seem to show that the coefficient of expansion ranges from 0.0000040 to 0.0000065, the latter figure applying at a temperature of 150 degrees F. and the former at approximately 50 degrees F. The exact figure, no doubt, will depend upon a number of factors, including the characteristics of the cement and aggregates, and the age of the concrete, and perhaps

at this time no more definite statement can be made of the coefficient of expansion of concrete subject to temperature change. If we accept our customary figure of 0.0000055, a length of concrete of 100 feet shrinks 0.0000055 $\times$ 100 $\times$ 100 = 0.055 feet, or 0.66 inches for a change in temperature of 100 degrees F. It necessarily follows that changes in length of a concrete pavement, produced either by temperature or moisture changes, must be accompanied by the production of

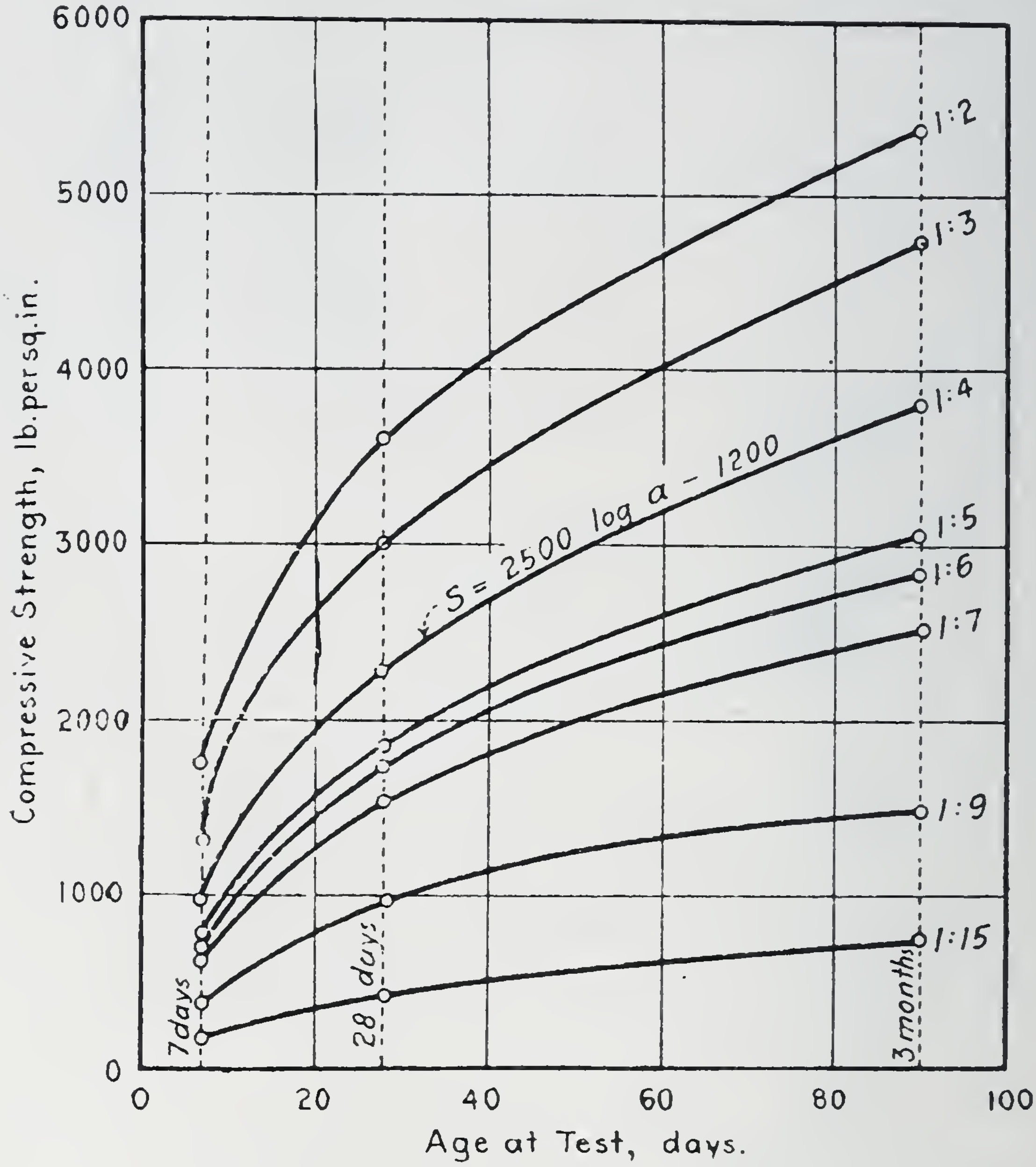


Fig. 2. Compressive Strength of Concrete.

direct tension or compression within the concrete. These stresses will be treated in detail elsewhere.

Compressive Strength of Concrete. Numerous experiments have been made on concrete cylinders to determine the effect of the different variables which affect the compressive strength. Perhaps the greatest amount of work along this line has been done under the direction of D. A. Abrams, of Lewis Institute, Chicago. In Fig. 2 there

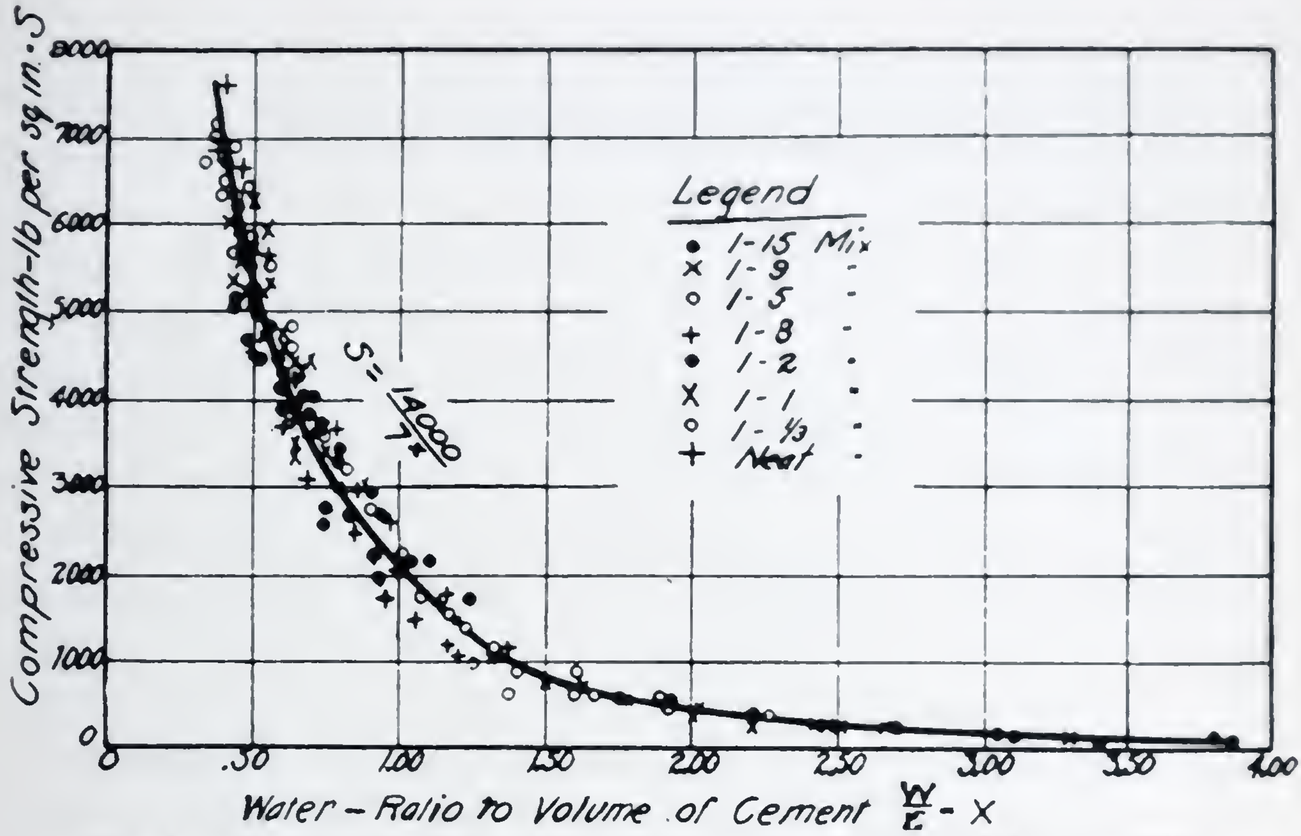


Fig. 3. Relation Between Strength of Concrete and Water Content.

is reproduced a set of curves taken from the Lewis Institute results. The curves in this figure show the rate of growth of compressive strength of the different mixtures of concrete, and in Fig. 3, also reproduced from Professor Abrams's results, is shown the relation between the compressive strength of concrete and the so-called "water-cement ratio." This curve is based on 28-day compression tests of 6- by 12-inch cylinders. It illustrates very strikingly that the strength of concrete depends principally upon the ratio of the volume of water to the volume of cement used in the mixture, irrespective of the pro-

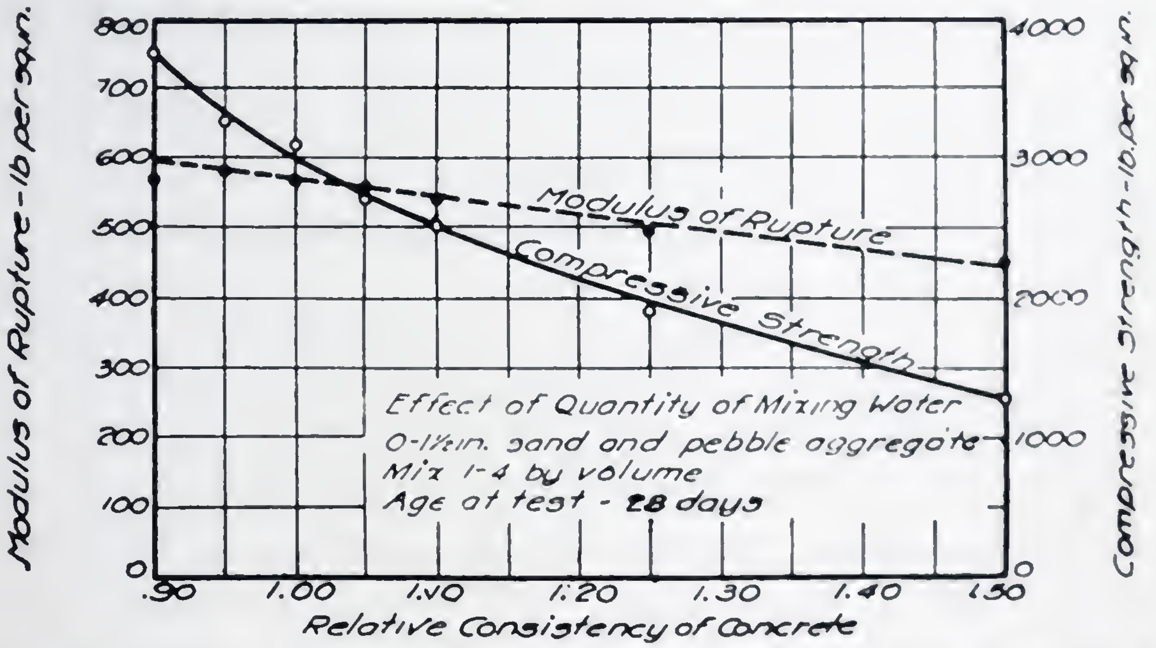


Fig. 4. Effect of Quantity of Mixing Water on Modulus of Rupture.

portions of that mixture so long as the mixture is "workable." Apparently 3000-pound concrete, such as is desirable for pavement purposes, requires a water-cement ratio of about 0.8, or about six gallons per bag of cement.

It is obviously impossible to go into the details of the various effects upon the strength of concrete of the variables to which it might be subjected. The strengths shown in the accompanying curves were obtained under conditions ideal for curing. It is desirable that the concrete used be so proportioned and cured that it will attain 3000 pounds at 28 days when cured under road conditions, and such variables as temperature of atmosphere during hardening and duration of curing both affect the resulting strength, irrespective of the consistency, proportions, condition of moisture of the specimen upon testing, and method of testing. Generally speaking, compressive strength of road concrete is not particularly important except in so far as it indicates the general quality of the concrete.

Modulus of Rupture. Perhaps the most important quality which road concrete must possess is that of high resistance to cross bending. When a crack forms in a concrete pavement this results either from direct tension or from cross bending. In Fig. 4 are shown results of cross-bending tests expressed in terms of modulus of rupture. The term modulus of rupture is applied to the stress which exists at the most remote fiber of the beam upon failure, the stress being calculated by the ordinary formula for flexure, $S = \frac{Mc}{I}$, where M = maximum bending moment; c = distance from neutral axis to most remote fiber; and I = moment of inertia of cross-section.

Judging from the curves herein shown, no direct relation can be stated between the compressive strength of concrete and the modulus of rupture. In view of the fact that high bending stresses are produced by heavy loads, pavement concrete must possess a high value for modulus of rupture, preferably not under 600 pounds per square inch at 28 days. As in the case of compression, the cross-breaking strength of concrete is affected by many variables. Perhaps one of the most significant effects, however, is that of the condition of moisture of the specimen at the time of testing. Recent experiments at Purdue University have shown that a beam which is completely saturated has a strength only 75 to 85 per cent. of that of a beam which is air dried

(See Fig. 5) and that the strength may be varied both above and below the dry strength, depending upon the depth of saturation of the concrete. There is included herewith a table[2] showing the influence of the depth of saturation on the strength of concrete beams as determined at Purdue University (See Table II).

Modulus of Elasticity. By modulus of elasticity we mean the ratio of unit stress to unit deformation, and this value directly indicates the relative stiffness of the concrete under the application of load. A typical modulus-of-elasticity curve is shown in Fig. 6. On this curve is shown the amount of deformation per inch of length for the different stresses applied. On the curve is likewise shown the permanent set which takes place in concrete after stress has been applied and again released. Concrete is not perfectly elastic, but yields permanently under load, and under a long application of load it has been shown by the investigations in the Bureau of Public Roads, and elsewhere, that this yielding is apt to continue. The modulus of elasticity of concrete in tension for practical purposes may be considered as identical with its value in compression. The value of the modulus of elasticity of road concrete varies greatly, depending on conditions, and ranges around approximately 2,500,000 to 5,000,000, or even higher. In a general way, high compressive strength is apt to be accompanied by a high value for modulus of elasticity.

Fatigue of Concrete. During the passage of heavy vehicles a concrete pavement is subjected to stress, then the stress is released or often reversed from compression to tension. On a heavily traveled road this happens several thousand times during a single day. It is thus evident that it is important to know something of the effect of fatigue on the behavior of concrete. A number of experiments have been performed along this line, notably by Purdue University, by the Illinois Department of Public Works, and also by the University of Maryland.

As indicated in Fig. 7, the Purdue tests seem to show that when a beam is not stressed beyond 54 per cent. of the modulus of rupture of the concrete it can be subjected indefinitely to reversals of stress of this magnitude. On the other hand, when the stress produced is in excess of this amount, comparatively few reversals can be applied before failure takes place. This applies to dry concrete alone. When

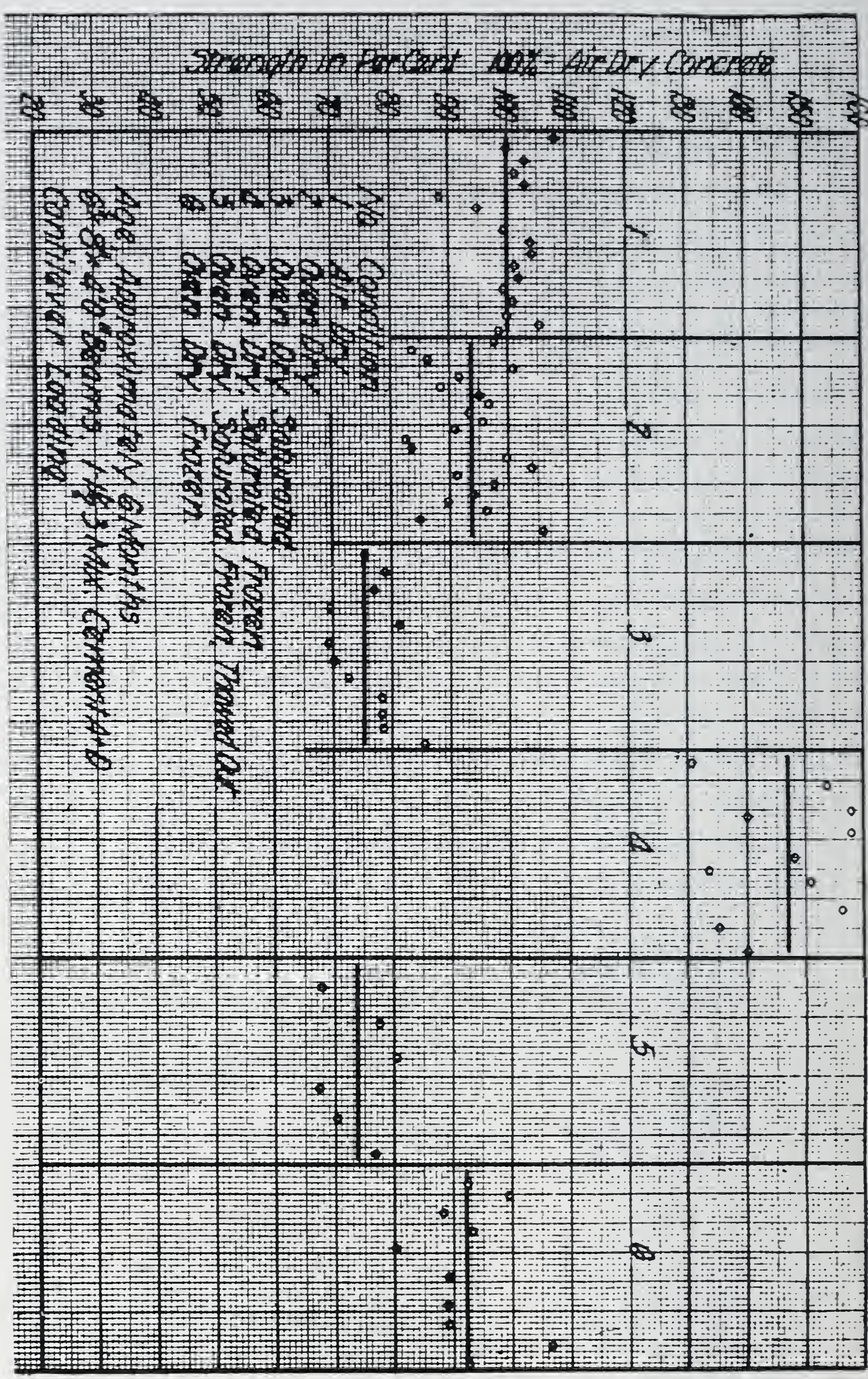


Fig. 5. Effect of Saturation and Freezing Upon Transverse Strength of Concrete.

TABLE II. MODULUS-OF-RUPTURE DATA OF WARPED BEAMS

Number of beams	Initial contraction in percentage	Condition at time of test	Visual height of water, in inches	Percentage deformation at time of test		Face loaded in tension	Modulus rupture cantilever loading			Modulus rupture one-third point loading			Modulus rupture percentage of grand average
				Wet face	Dry face		Number of values	Numerical values	Percentage of reference values	Number of values	Numerical values	Percentage of reference values	
Series No. 1. 6 in. by 8 in. by 4 ft. 0 in. beams. 1 : $1\frac{1}{2}$: 3 mix. Cements A and D. Age, 4 months. Oven dry.													
5	0.022	Dry	....	....	....	....	20	720	100	....	....	....	100
2	0.022	Saturated	....	+0.020	....	....	10	616	85	....	....	....	85
5	0.022	Saturated to 2 in. depth	3	+0.019	−0.0016	Dry	19	789	109	....	....	....	109
5	0.022	Saturated to 2 in. depth	3	+0.019	−0.0016	Wet	19	602	83	....	....	....	83
Series No. 2. 7 in. by 4 in. by 4 ft. 0 in. beams. 1 : 2 : $3\frac{1}{2}$ mix. Cement F. Age 3 months. Air dry.													
3	0.041	Dry	....	....	....	....	8	839	100	3	738	100	100
3	0.041	Saturated	....	+0.017	....	....	8	672	80	2	506	68	77
4	0.041	Saturated to $2\frac{1}{3}$ in. depth	$3\frac{1}{2}$	+0.024	+0.0035	Dry	12	750	89	4	614	83	87
4	0.041	Saturated to $2\frac{1}{3}$ in. depth	$3\frac{1}{2}$	+0.024	+0.0035	Wet	12	618	73	4	472	64	71
Series No. 3. 7 in. by 4 in. by 4 ft. 0 in. beams. 1 : 2 : $3\frac{1}{2}$ mix. Cement F. Age 3 months. Oven dry.													
8	0.049	Dry	....	....	....	....	20	780	100	7	652	100	100
7	0.049	Saturated	....	+0.018	....	....	19	671	85	5	544	83	85
3	0.049	Saturated to $2\frac{1}{2}$ in. depth	4	+0.021	+0.016	Dry	10	637	81	3	511	78	80
3	0.049	Saturated to $2\frac{1}{2}$ in. depth	4	+0.021	+0.016	Wet	10	609	78	3	478	72	76

TABLE II. *Continued*

Series No. 4. 7 in. by 4 in. by 4 ft. 0 in. beams. 1 : 2 : 3½ mix. Cement F. Age 7 months.
Oven dry, 3 months; Air dry, 4 months.

Number of beams	Initial contraction in percentage	Condition at time of test	Visual height of water, in inches	Percentage deformation at time of test		Face loaded in tension	Modulus rupture cantilever loading			Modulus rupture one-third point loading			Modulus rupture percentage of grand average
				Wet face	Dry face		Number of values	Numerical values	Percentage of reference values	Number of values	Numerical values	Percentage of reference values	
1	0.037	Dry	....	....	....	....	4	809	100	1	651	100	100
1	0.041	Saturated	....	+0.014	....	....	3	699	86	1	553	85	86
1	0.043	Saturated to 1½ in. depth	3½	+0.017	—0.004	Dry	3	961	118	1	742	114	117
2	0.040	Saturated to 2¾ in. depth	4	+0.015	+0.0003	Dry	7	774	95	1	646	99	96
1	0.040	Saturated to 4 in. depth	5	+0.018	+0.0017	Dry	3	670	82	1	565	86	83

Series No. 5. 7 in. by 4 in. by 4 ft. 0 in. beams. 1 : 2 : 3½ mix. Cement F. Age 7 months. Air dry.

Number of beams	Initial contraction in percentage	Condition at time of test	Visual height of water, in inches	Wet face	Dry face	Face loaded in tension	Cantilever: Number of values	Cantilever: Numerical values	Cantilever: Percentage of reference values	One-third point: Number of values	One-third point: Numerical values	One-third point: Percentage of reference values	Modulus rupture percentage of grand average
2	0.051	Dry	....	....	....	....	6	825	100	2	731	100	100
1	0.047	Saturated	....	+0.021	....	....	3	733	88	1	633	86	88
1	0.048	Bottom Wet	2	+0.020	—0.0065	Dry	3	1066	129	1	884	121	127
2	0.052	Saturated to 1¼ in. depth	2½	+0.027	—0.0048	Dry	6	910	110	2	734	100	107
1	0.054	Saturated to 2½ in. depth	3½	+0.032	+0.0012	Dry	4	714	86	1	651	89	87

the concrete is saturated the results recently reported by Dr. Hatt are very significant. He reports as follows:

"The saturated beams showed 89 per cent of the static strength of the dry beams.

Beam No. 162 failed at 200 reversals under a load equal to 55 per cent of the once applied load; duration of test 1/3 hour.

Beam No. 161 failed at 8,400 reversals at 50 per cent load; duration ½ day.

Beam No. 165 at 17,200 reversals of 50 per cent; duration 1¼ day.

Beam No. 164 at 71,700 reversals of 40 per cent; duration 5 days.

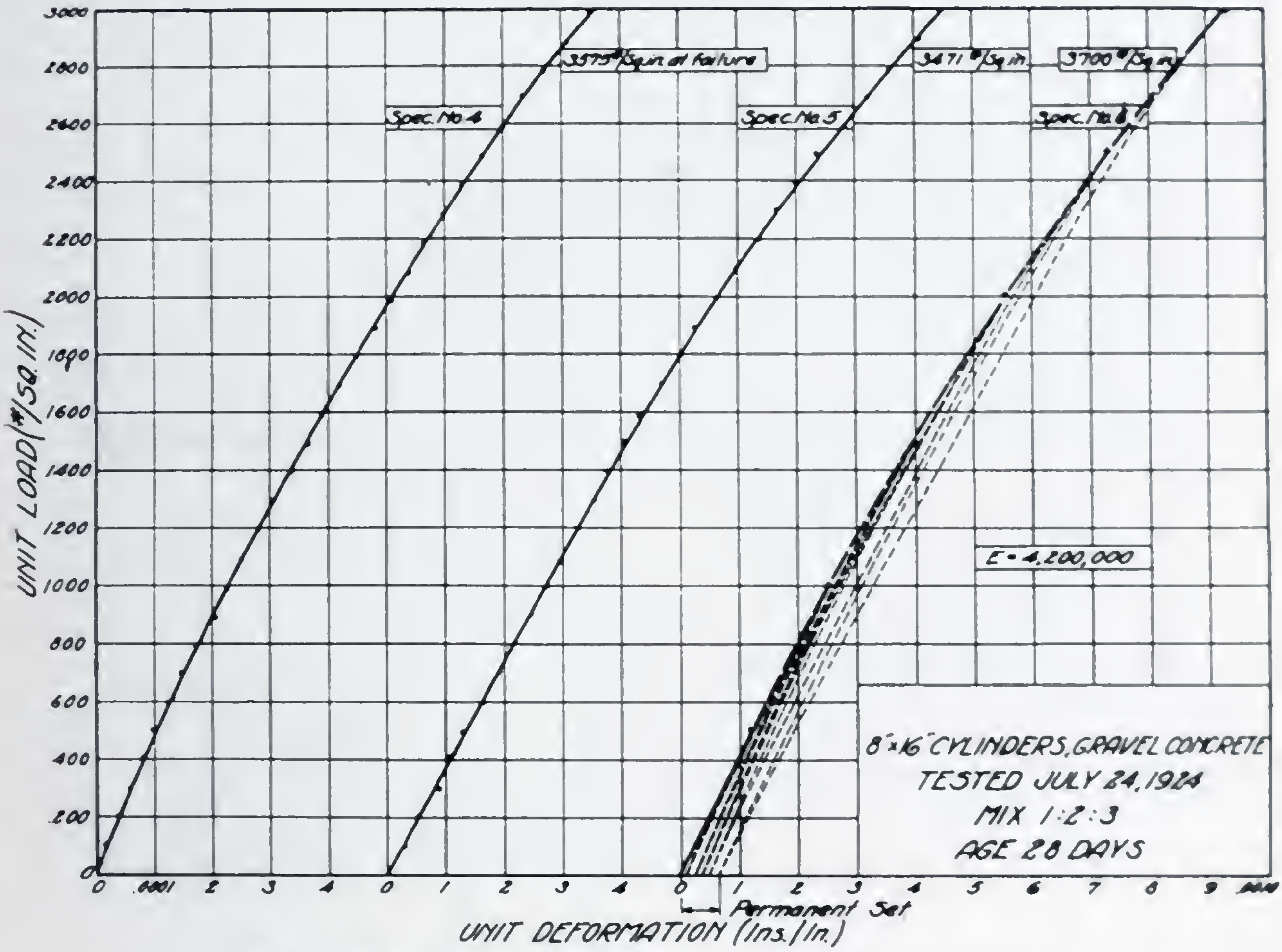


Fig. 6. Modulus-of-Elasticity Curve for Concrete.

These tests are being continued. It would appear that something less than 55 per cent of the static strength of dry concrete should be the working strength of the saturated concrete of road slabs."

Tests such as cited above indicate the value for unit stress beyond which it would not be safe to load a concrete pavement if cracking under loads is to be prevented. Apparently if the concrete is to be kept in a rather dry condition, the unit stress should not exceed 50 per cent. of the modulus of rupture. In a saturated condition, even 40 per cent. is none too low a unit stress to use. It is perhaps generally

the case in most concrete roads that the concrete does not remain saturated for any great length of time; there are exceptions, however.

Tensile Strength of Concrete. There are times when a concrete roadway is subjected to direct tension. It is important, therefore, that something of the tensile resistance of concrete be considered in connection with concrete road design. A few scattered tests have been made on concrete in tension, and in general these results might be summarized by the statement that, roughly, concrete in direct tension has approximately one-twelfth of its strength in direct compression. On this basis the tensile strength of concrete which has a compressive

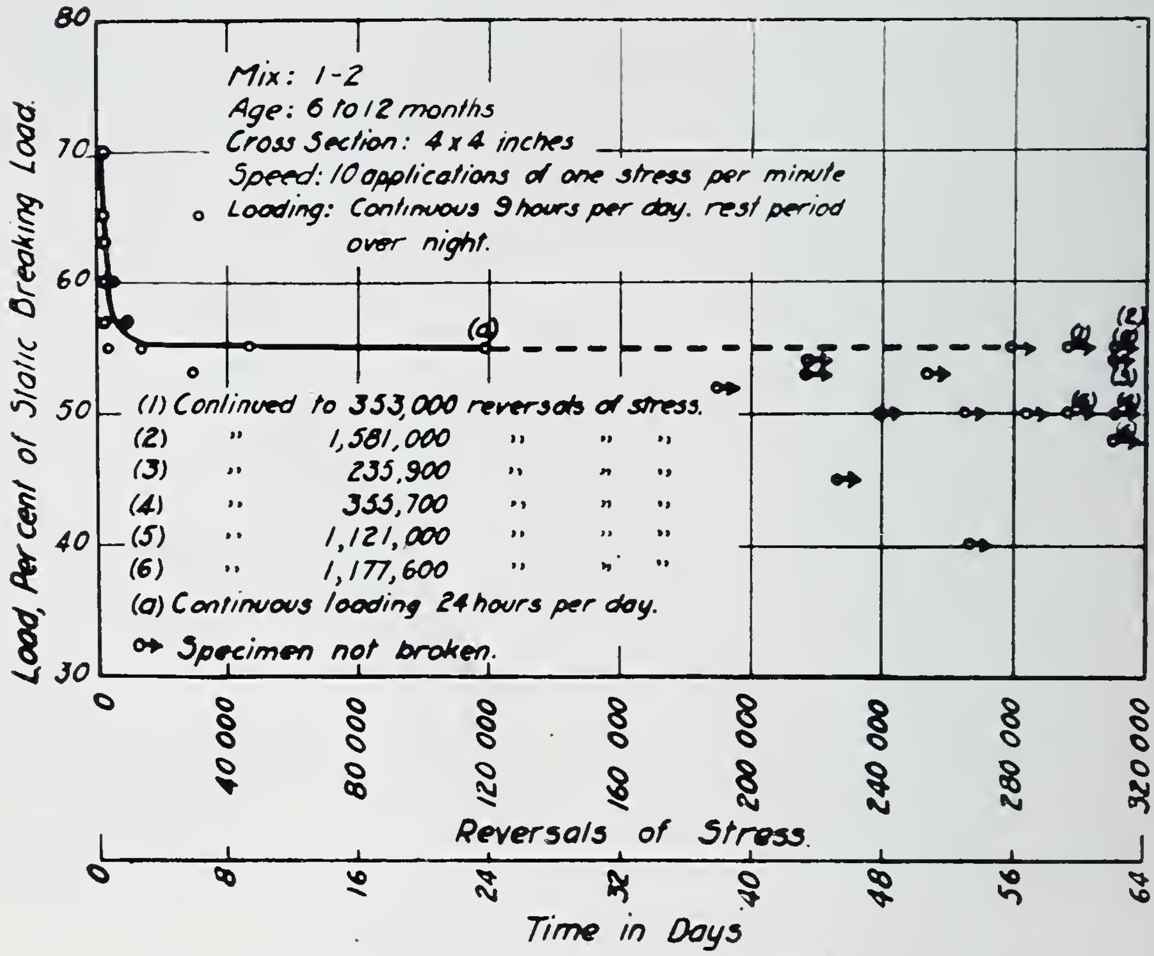


Fig. 7. Fatigue Endurance Limit of Cement-Mortar Beams.

strength of 3000 pounds at 28 days would be approximately as follows:

Days	Pounds
7	100
15	194
28	250
90	400

It is quite likely that there might be considerable variation from these figures, depending upon the large number of variables to which the concrete might ordinarily be subjected.

FORCES TO BE RESISTED BY A CONCRETE PAVEMENT

Having considered some of the fundamental properties of concrete, we are now ready to study the forces to which a concrete pavement is subjected and to study the design of the pavement as it is influenced by these forces and by the properties inherent in the concrete itself.

Friction on the Subgrade. We have stated that as soon as the moisture begins to dry out of the concrete it begins to shrink and therefore to move over the subgrade. Likewise we know that with a fall in temperature contraction takes place, resulting in movement of the concrete over the subgrade. This movement is resisted by friction

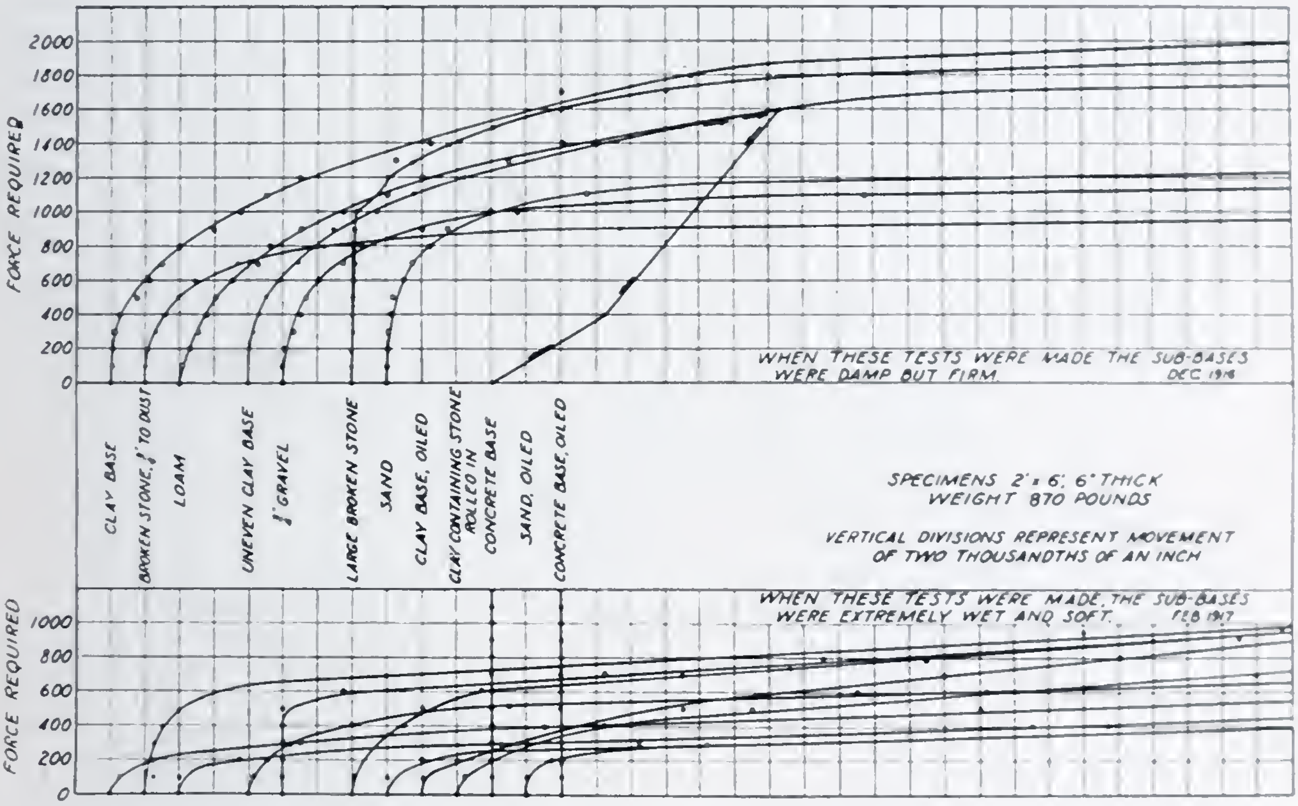


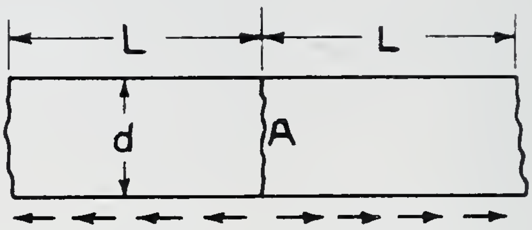
Fig. 8. Subgrade Friction Tests.

between the concrete and the subgrade. The magnitude of this friction was determined by the writer in the Bureau of Public Roads a number of years ago and its value is shown in Fig. 8[3]. The values for the coefficient of friction are shown in Table III, the last column of which is most significant. It is seen that the friction might vary considerably, depending upon the character of the subgrade and also upon its degree of saturation. Roughly, it might be said that the coefficient of friction varies between 1.0 and 2.0. With a dry subgrade it is quite likely that the value of 2.0 is not unusual and it can be higher.

Let us investigate the action of the forces of friction in producing transverse cracking in a concrete pavement. Suppose that the curing of the concrete is stopped after 10 days and that shrinkage develops due to this cause and also to falling temperature.

Let f equal coefficient of friction = 2.0. Assume the tensile strength of the concrete S at this period, 10 days, equals 100 pounds per square inch. At the cross-section at which the tensile resistance of the concrete is just exceeded by the total force of friction a crack will take place. This is expressed algebraically in Fig. 9, which is concerned with the distance between transverse cracks in a plain eight-inch concrete surface 18 inches wide.

It is assumed in the calculations shown in Fig. 9 that the shrinkage or contraction does not begin until the end of 10 days. Suppose,



Let S = tensile strength of concrete when failure takes place at A.

Let f = coef. of subgrade friction.

Just before failure takes place at A:-

$$Sd\,12 = Lfw \quad \text{or} \quad L = \frac{Sd\,12}{fw}$$

Let d = 8" and f = 2.0, S = 100# per □" at 10 to 15 days

$$L = \frac{100 \times 8 \times 12}{2 \times 100} = 48'$$

Fig. 9. Transverse Crack Spacing.

however, that there have been conditions of high shrinkage due to insufficient curing or too low temperatures occurring at the end of 24 hours, at which time the tensile strength of the concrete might be only 40 to 50 pounds per square inch, or approximately one-half of that at 10 days. This would lead to cracking transversely, with cracks approximately 20 to 24 feet apart. The above calculations are necessarily inexact, for the assumptions are subject to a considerable range of value. They do show, however, that the behavior of the pavement will depend not only upon the design, but also on the curing treatment that the pavement receives after being built. It is evidently important that curing be continued until high tensile strength is attained in order that the concrete may be kept expanded until it is

TABLE III. FRICTIONAL RESISTANCE OF CONCRETE

Frictional resistance of concrete on various sub-bases in damp but firm condition.

Kind of base	Movement	Force	Coefficient	Movement	Force	Coefficient	Movement	Force	Coefficient
	Inches	Pounds		Inches	Pounds		Inches	Pounds	
Level clay	0.001	480	0.55	0.01	1,130	1.3	0.05	1,800	2.07
Uneven clay	0.001	500	0.57	0.01	1,120	1.29	0.05	1,800	2.07
Loam	0.001	300	0.34	0.01	1,030	1.18	0.05	1,800	2.07
Level sand	0.001	600	0.69	0.01	1,080	1.24	0.05	1,200	1.38
¾-inch gravel	0.001	450	0.52	0.01	960	1.10	0.05	1,100	1.26
¾-inch broken stone	0.001	380	0.44	0.01	800	0.92	0.05	950	1.09
3-inch broken stone	0.001	1,060	1.84	0.01	1,550	1.78	0.05	1,900	2.18

Frictional resistance of concrete on various sub-bases in thoroughly saturated condition with water and surrounding ground exceedingly soft.

Kind of base	Movement	Force	Coefficient	Movement	Force	Coefficient	Movement	Force	Coefficient	Movement	Force	Coefficient
	Inches	Pounds		Inches	Pounds		Inches	Pounds		Inches	Pounds	
Level clay	0.001	120	0.14	0.01	300	0.35	0.05	500	0.58	1.5	950	1.09
Uneven clay	0.001	200	0.23	0.01	460	0.53	0.05	620	0.71	1.4	925	1.06
Loam	0.001	150	0.17	0.01	260	0.3	0.05	410	0.47	0.75	925	1.06
Level sand	0.001	140	0.16	0.01	280	0.32	0.05	400	0.46	0.75	875	1.00
¾-inch gravel	0.001	510	0.58	0.01	640	0.73	0.05	950	1.01	0.5	1,050	1.2
¾-inch broken stone	0.001	400	0.46	0.01	660	0.76	0.05	940	1.08	2.0	1,160	1.33
3-inch broken stone	0.001	240	0.28	0.01	630	0.73	0.05	900	1.04	0.875	1,625	1.87
Oiled clay	0.001	150	0.17	0.01	410	0.47	0.05	850	0.98	1.25	1,425	1.64
Clay and cobblestones	0.001	140	0.16	0.01	410	0.47	0.05	710	0.82	1.75	1,260	1.45
Concrete base	0.001	2,500 +	2.9 +	0.00	2,500 +	2.9 +	0.00	2,500 +	2.9 +	0.00	2,500 +	2.9 +
Sand, oiled	0.001	180	0.21	0.01	280	0.32	0.05	480	0.55	0.375	800	0.92
Concrete, oiled	0.000	2,500 +	2.9 +	0.00	2,500 +	2.9 +	0.00	2,500 +	2.9 +	0.00	2,500 +	2.9 +

ready to receive tensile stress. It is also important that the coefficient of friction between the subgrade and the pavement be reduced to a minimum, for this, too, influences the frequency of cracking. Careful preparation of the subgrade helps to reduce transverse cracking.

Warping of the Concrete. Since concrete changes in length due to both temperature and moisture, it becomes quite apparent that if either of these effects is more prevalent on the top of the slab than on the bottom there will be greater change in length of the slab at the top than at the bottom, and consequently it must warp. At night the slab generally cools more on the surface than at the bottom. The top surface therefore contracts, and for this reason it is often the case that the edges of the slab and the corners are curled up away from the sub-

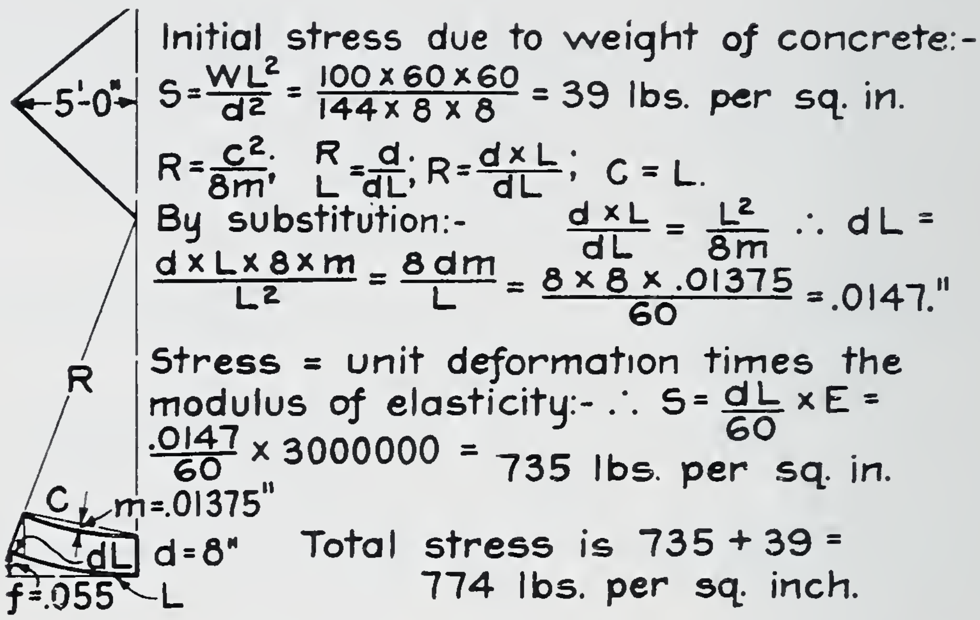


Fig. 10. Stress Produced at a Corner by Traffic and Warping.

grade. During the day the reverse is true; the top surface is heated and the bottom surface remains more or less at a constant temperature and the slab bears heavily on the subgrade at the sides and corners. These facts are not based merely on theory, but they have been demonstrated a number of times in the Pittsburg test (California), the Bates test (Illinois), at Arlington, and elsewhere. It is readily apparent that warping of the slab might have considerable effect on the pavement, for when it is warped away from the subgrade heavy passing vehicles bend it back into contact with the subgrade, and in so doing cause high stresses. In Fig. 10 are shown calculations illustrating the high stresses which might result from traffic which bends the corner of an eight-inch slab back into contact with the sub-

grade after it has been warped upward 0.055 of an inch, due to temperature. Although the conditions of support for the slab may have been assumed in a somewhat severe manner, nevertheless the possibilities for high stress are evident.

EFFECT OF WHEEL-LOADS

In studying the effect of wheel-loads on pavements it is pertinent to inquire as to just what wheel-loads are to be expected on concrete pavements, and, moreover, how those wheel-loads are distributed on the pavement.

Traffic Census Studies. A number of studies have been made by various states, many of them in co-operation with the Bureau of Public Roads, in order to determine the distribution of traffic over state highway systems. Fig. 11 illustrates the average daily distribution in the state of Pennsylvania.

In taking these traffic censuses information was obtained as to the point of origin and destination of the vehicles, and each vehicle was likewise weighed in order to determine wheel-load distribution. In all the studies thus far made there were certain outstanding facts developed which are significant from the standpoint of concrete highway design. Perhaps the most significant is that on only a very small percentage of the highways are to be found the extremely heavy trucks, and these are relatively few in number. In general, the very heaviest trucks do not travel very far away from the large centers of population, or they are found to be confined to certain routes which they travel because of the location of a certain industry such as a crushing plant or coal-mine. Certain principal routes are apt to have comparatively heavy trucks on them, although not the heaviest, while other secondary routes may never receive vehicles in excess of two or three tons capacity. Apparently the distribution of heavy motor-vehicle truck travel is somewhat automatically governed by the economy with which such vehicles can be operated, and no doubt by other considerations.

The main point, however, is that not all pavements need be designed for the heaviest loads which exist in the state, but due recognition should be taken of distribution of traffic as revealed by a properly taken traffic census, making sufficient allowance for increased weight of traffic in the future. When considering the design of a con-

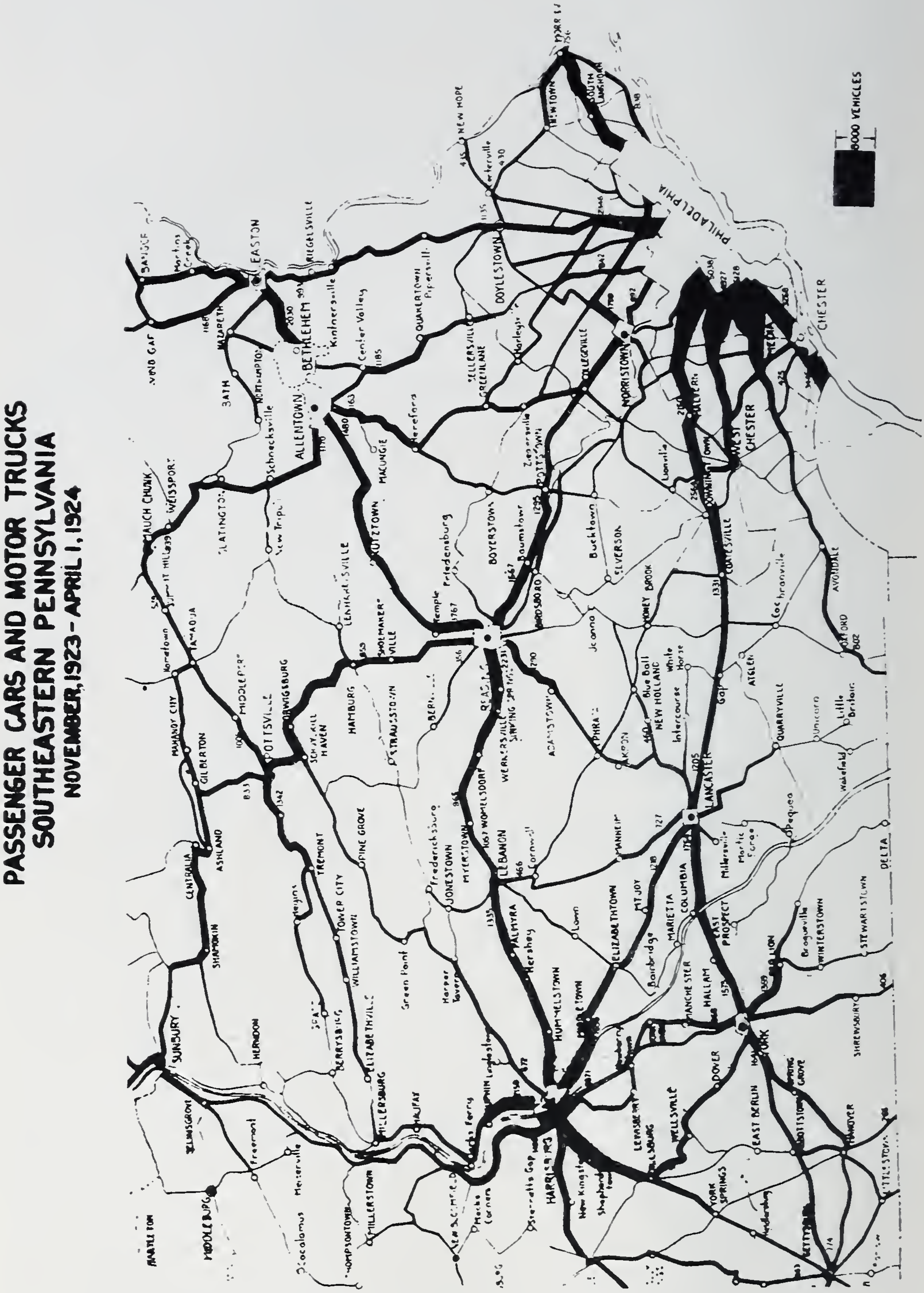


Fig. 11. Traffic Distribution in Pennsylvania.

crete pavement, however, it is perhaps unwise to make the pavement any thinner than that requisite for carrying a truck of three-ton capacity.

The following figures indicate the wheel-loads on two different routes in Pennsylvania. The figures are based on traffic census data from a heavy-traffic and a medium-traffic road.

The following figures are from Route No. 142, Philadelphia to Ardmore, Pa., with daily truck traffic, 600 trucks:

Loads	Percentage	Maximum wheel-loads
18,000 and under................	90.5	5,500
18,000–24,000	6.4	8,500
Over 24,000	2.1	13,500

The following are from Route No. 84, Erie to Meadville, Pa., with daily truck traffic, 125 trucks:

Loads	Percentage	Maximum wheel-loads
18,000 and under	98.1	5500
18,000–24,000	1.9	8500

If these figures alone are to be used for the load assumptions for design purposes it is obvious that Route No. 142 would require a heavier road than route No. 84. The best prediction possible on the basis of the present traffic census, the industrial conditions in the surrounding territory, the growth of population and other pertinent factors, should be made to determine the maximum wheel-load to be used for calculating the cross-section design.

Distribution of Traffic over Width of Pavement. Before considering the effect of the traffic on a concrete pavement it will be well to inquire into the position on the pavement which the traffic ordinarily assumes. Studies have just been completed by the Bureau of Public Roads which throw considerable light on this question. The studies consisted merely of counting the vehicles which passed over given marks painted on the pavement. In Fig. 12 is shown a curve which is somewhat typical of an 18-foot concrete pavement. This test was made on a level pavement with shoulders in good condition. The average speed was 12 to 25 miles per hour, for trucks and passenger vehicles, respectively.

The traffic will be distributed differently, of course, depending upon its intensity, upon the width of the shoulders, the presence of

vertical and horizontal curves, and other influences. In general, however, the traffic is apt to run anywhere on the pavement, although the most frequent wheel-load passage is at the center. Where there is no center longitudinal joint it is seen that the truck traffic is concentrated approximately 18 inches to two feet away from the edge of the pavement with the high intensity of traffic, due to the passage of wheels in opposite directions, at the center of the pavement. A center longi-

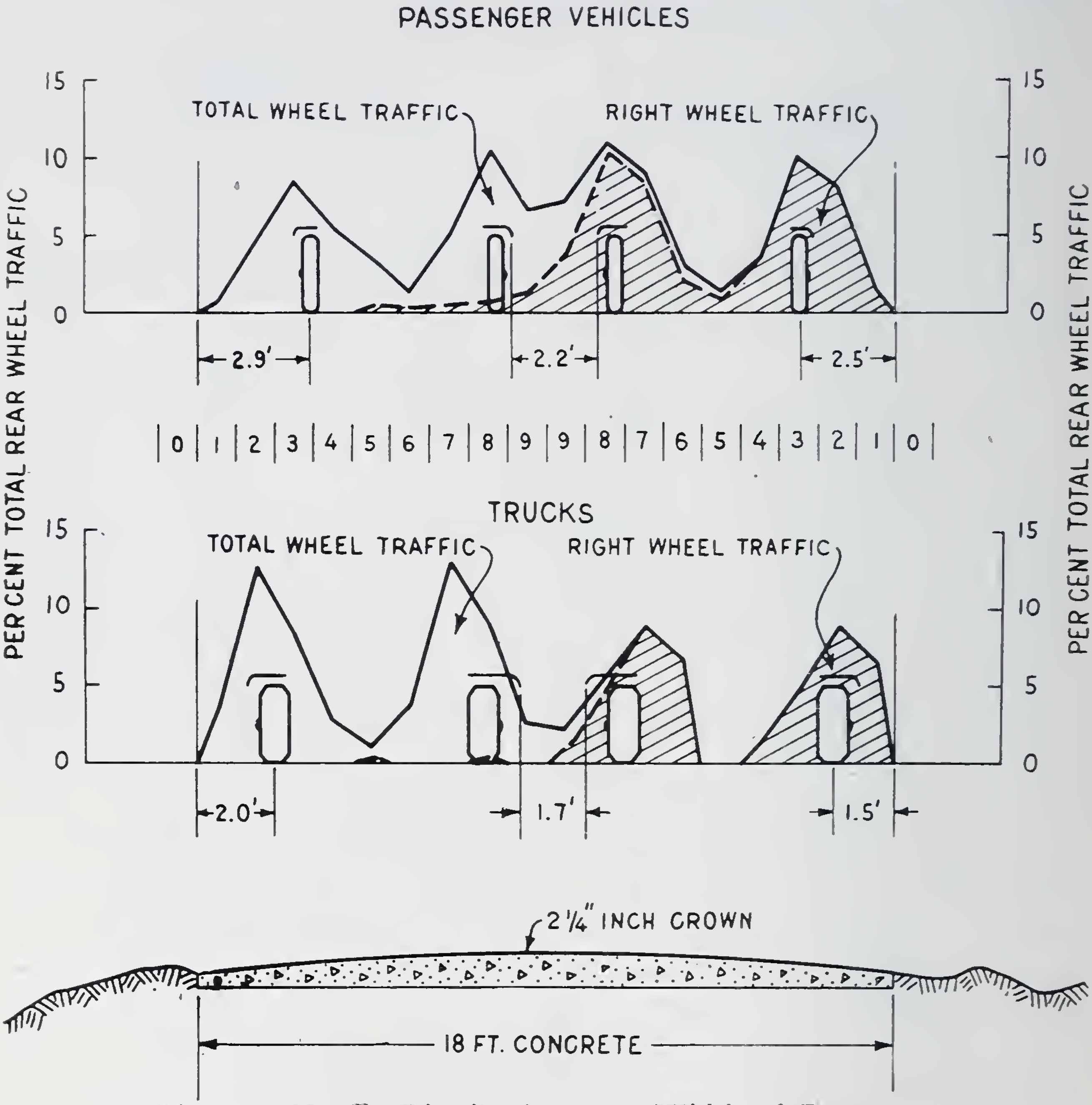


Fig. 12. Traffic Distribution over Width of Pavement.

tudinal joint does not seem to help this condition very much, so that, in general, it might be said that a large number of trucks will trail along a line 18 inches from the edge of the pavement, some of them will run out at the extreme edge, and a very large number of the wheel-loads will be applied near the center of the pavement. Since the heavy vehicles are found to run everywhere on the pavement, it is

important that the design be such that the pavement will not be over-stressed no matter what the position of the wheel-load.

Investigations on the Design of Concrete Pavements. There have been three major investigations, all of which throw light on the load-carrying capacity of different cross-section designs. They are the Pittsburg test road in California, the Bates test road* in Illinois, and the experiments of the Bureau of Public Roads at Arlington Experimental Farm, Arlington, Va. The cross-section which all of these experiments point to as the strongest for supporting heavy loads everywhere is that having a thickened edge.

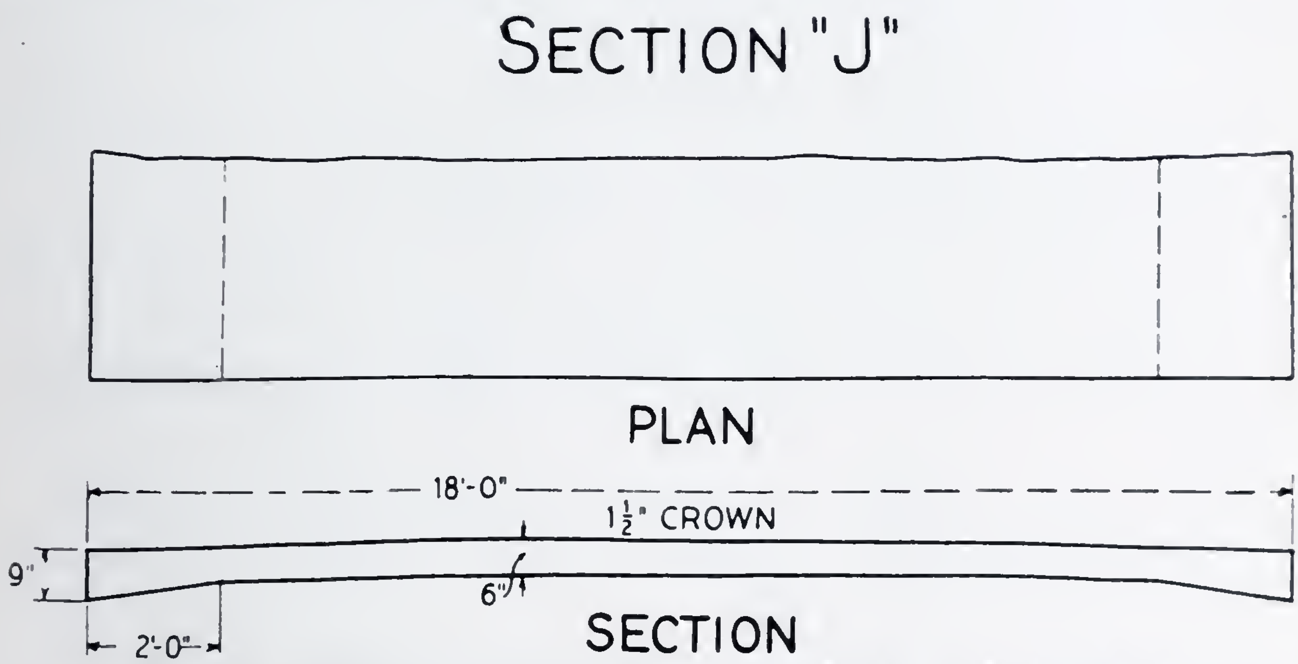


Fig. 13. Thickened-Edge Design of the Pittsburg Road Tests.

In Fig. 13 is shown the cross-section which has given the highest rating as a result of the Pittsburg test road. This cross-section was originally developed by the California Highway Commission, but was not used to any great extent. As a result of the Bates road test, in which a number of different cross-sections of pavement were subjected to gradually increasing loading, a design similar to the California design was finally selected as being of the highest all-round strength for a given amount of concrete.

The tests at Arlington include tests to destruction on both impact and static load of concrete and reinforced concrete of different designs, and also the measurement of stresses on full-sized pavement sections under the action of motor-truck loading. The impact and static load tests on slabs have been described in detail elsewhere.[1] In brief, how-

*Proceedings, v. 39, p. 340.

ever, the impact tests were made on slabs seven feet square, laid directly on a well-drained and also on a saturated subgrade. Loads were applied by the impact of a special machine simulating motor-truck impact. A number of these slabs were later tested in other positions under static load. The main conclusions of value in connection with concrete and reinforced concrete pavement design are stated as follows:

"The resistance of the road slab depends in part upon the supporting value of the subgrade. A subgrade of high supporting value materially increases the resistance to impact.

Impact resistance of rigid slabs varies neither directly as the depth of the slab nor as the square of the depth but as some power less than two.

In general, plain concrete slabs show no more resistance to impact delivered at the edge than to impact delivered at a corner.

Transverse cracks and longitudinal cracks near the sides of a road slab may be caused by impact delivered at the edge of the slab.

Plain concrete of 1:3:6 mix offers resistance to impact ranging from about 60 per cent to 80 per cent of the resistance of plain concrete of 1:1½:3 mix. The lean mix also shows more variation in strength.

Reinforcing steel in concrete slabs, if present in sufficient amount and so placed as to receive tensile stress, adds to the resistance of the slab to impact.

Reinforcing steel placed longitudinally and transversely in equal percentages is more effective in preventing corner failures than the same amount placed in one direction.

For a given percentage of steel, small deformed rods closely spaced seem to be more effective than large deformed rods widely spaced."

From the static load tests[5] it has been concluded that:

"1. The static resistance of both the corners and the edges of the rigid slabs is affected by the nature of the subgrade; the more resistant the subgrade to load, the greater the resistance of the slab, and vice versa.

2. The resistance of the rigid slabs to static loads does not vary with the square of the depth but as some power greater than one and less than two. About 1.75 is the average value, the exponent being higher for slabs on the wet subgrade and lower for those on the dry subgrade.

3. The corners and edges of concrete slabs of the size and thickness tested offer about the same degree of resistance to static loads.

4. The presence of mesh reinforcement as employed in the slabs under consideration does not increase the load-carrying capacity of concrete slabs but does give rise to a tendency to hold together and resist complete failure after initial or elastic failure has taken place."

Stress Measurements. Special stress measurements have been made by the Bureau of Public Roads at Arlington and elsewhere in

several parts of the country for the purpose of determining the maximum deformations to be expected in different parts of pavements or different designs under actual heavy motor-truck loading. The vehicles were purposely run in different positions on the slab with the wheels tracing along the outer edge and along lines at different distances from that edge. As a result of these measurements it has been possible to plot maximum stresses occurring in slabs of uniform thickness, and a typical set of such deformations is shown in Fig. 14.

These readings are very illuminating, for they show very much

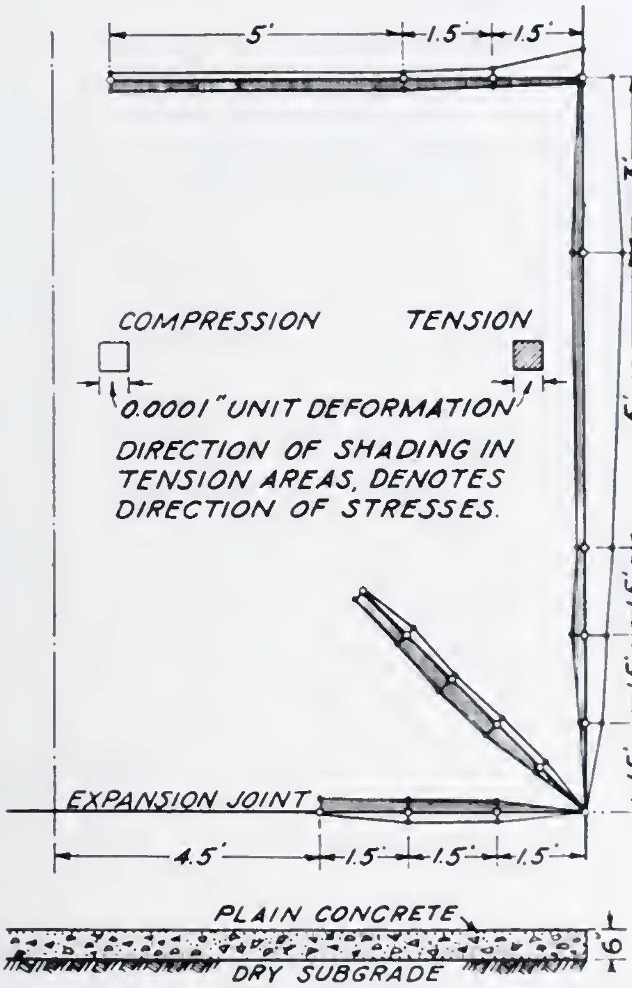


Fig. 14. Maximum Deformations in Top of Concrete Pavement Under Traffic.

higher stresses along the edge of the slab than at the center, thus bearing out the conclusions reached from the Pittsburgh and Bates road tests that it is well to strengthen the edge of the slab in order that it may be sufficiently resistant to heavy loads. It is interesting to note from these curves that the very highest tension occurs at the edge of the slab at the bottom, very likely directly under a heavy wheel-load. There can also be high tension at the top of the slab at the edge, occurring in all probability several feet away from the heavy wheel-loads.

High tension can also exist at a corner at the top of the slab. More recent readings of a similar character taken on a pavement of the Illinois cross-section with a center thickness of approximately 0.7 of the edge thickness show stresses at the center not greatly different from those at the edge, thus indicating that when a center longitudinal joint is used the center thickness should be approximately 0.7 of the edge thickness. The stress readings for this slab are illustrated in Fig. 15, which shows maximum unit deformations under a gross

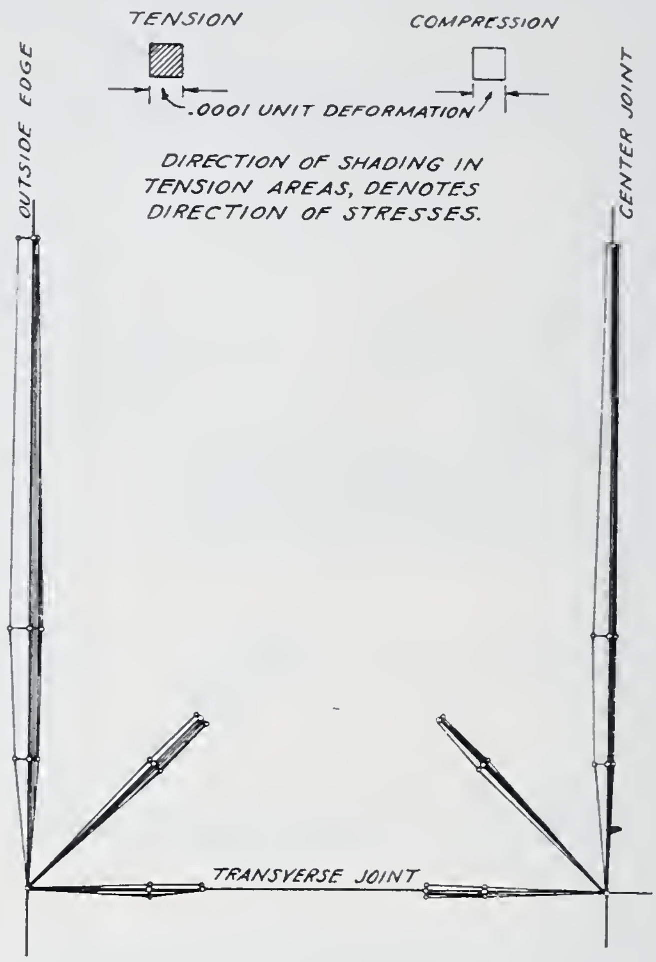


Fig. 15. Deformations in Thickened-Edge Pavement (Cook County Report).

load of 25,300 pounds (wheel-load, 8750 pounds). The mix was 1:2:3.5, and the age three months.

Formulæ for Design of Cross-Section. In the Bates road test, the traffic was purposely run with the rear wheels trailing along the edge of the slab, and a large number of corner breaks occurred. Naturally, the thicker the slab at the edge, the greater was the wheel-load which that slab was capable of carrying. The details of this investigation have already been published. The principal conclusion arrived at, however, is that for the subgrade conditions existing at the Bates road and common to Illinois it is now possible to predict the load

which will cause failure of the slab at the corner. This is accomplished merely by considering the corners formed by transverse joints or transverse cracks as unsupported cantilever beams of uniform strength and using the flexure formula for this condition. The prevention of corner cracking is considered important because, when a small area of concrete is formed thereby, a rapid and progressive failure results. Laboratory tests on concrete have shown that for dry concrete it is possible to apply repeated stress almost indefinitely up to slightly more than 50 per cent. of the modulus of rupture without

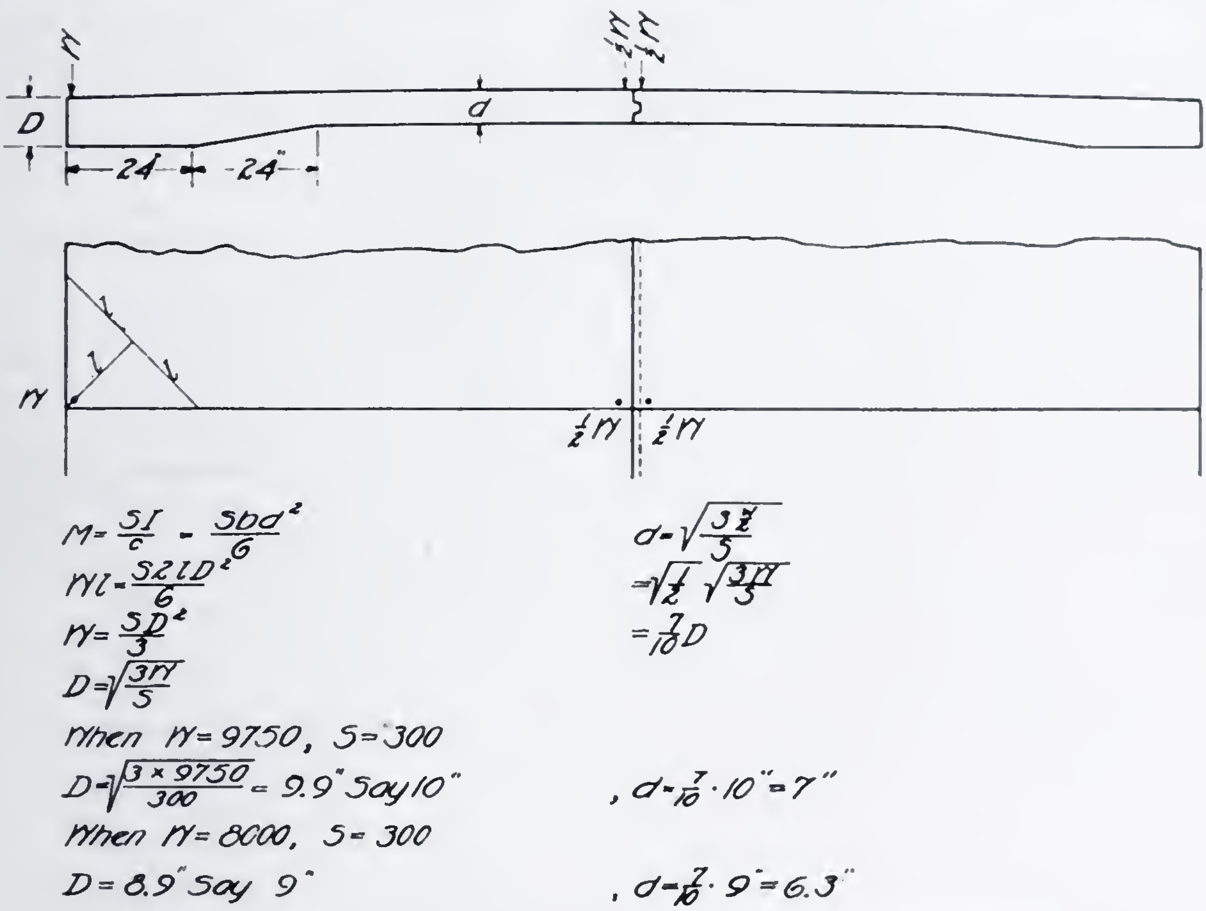


Fig. 16. Calculation of Slab Thickness by Corner Theory.

causing failure; whereas, if the stress in the concrete exceeds approximately 50 to 55 per cent. of the modulus of rupture, failure is apt to take place after a comparatively few load applications. This suggests immediately that it is safe to design the corners of a concrete pavement on the basis of a cantilever beam of uniform strength, the load being applied at the extreme corner and the unit stress not exceeding 50 per cent. of the modulus of rupture.

In Fig. 16 there is shown an analysis for these assumed conditions. Where a center longitudinal joint is used with tongue-and-groove joint, or with efficient dowel construction for transferring load

across the joint, it can be considered that two corners are supporting a single wheel-load with the result shown in Fig. 16, the center thickness equaling 0.7 of the edge thickness. Examples of the application of this formula to given load conditions are also illustrated in Fig. 16.

It is to be acknowledged that the above formulæ are only approximate, for they neglect a number of factors which are known to be present. A short discussion of these factors might be given as follows:

a. The formula neglects any support of the load from the subgrade. Undoubtedly there are times when the corners of the slab are, for practical purposes, unsupported. On the other hand, it is also probably true that a large percentage of the time the subgrade does offer material support. For the worst conditions the assumption of an unsupported cantilever is probably not too severe.

b. Stress measurements indicate that higher tension is to be expected longitudinally along the edge of the slab than at the corner; therefore, the initial crack is apt to occur first as a transverse crack starting at the edge of the slab. Thus when the pavement is designed on the basis of the corner formula a higher tensile stress is apt to be produced along the edge of the slab than would be indicated by the corner formula which is concerned with the diagonal stress at the corner.

c. The formula assumes that the load is applied statically. This neglects the fact that conditions are very often not ideal with regard to smoothness or to condition of truck tires. Impact does exist, especially with rapidly moving vehicles equipped with solid tires. The effect of this impact is probably offset to some extent by the assumption of no subgrade support and also by the severe assumption that the load is applied at the extreme corner. As shown by actual traffic surveys and illustrated in Fig. 12, many of the vehicles never run with their wheels at the extreme corners.

d. The results of tests on fatigue of concrete show that concrete is safe against failure if the unit stress does not exceed 50 per cent. of the modulus of rupture. This applies to dry concrete. When the concrete is saturated, however, failure takes place much more quickly. It has been stated, for instance, that whereas 300,000 applications of stress, equivalent to 53 per cent. of the modulus of rupture, were applied to dry concrete, only 3000 to 8000 applications of a similar stress were necessary to produce failure on wet concrete.

e. In calculating the corner as a beam of uniform strength, it is assumed that the thickness is constant across the width of the cross-section at each corner. In order that this assumption may hold true it will be necessary to have a constant edge thickness over several feet, measured from the edge of the slab. Actually such a cross-section is practically never used.

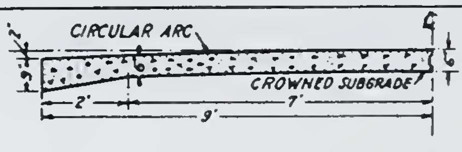
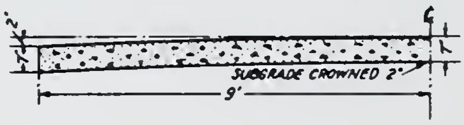
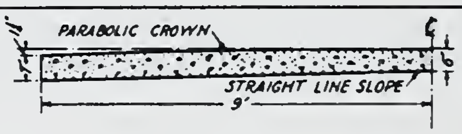
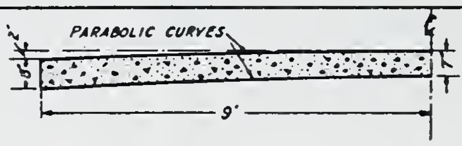
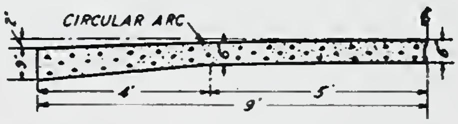
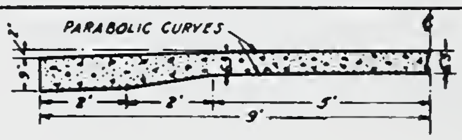
The net effect of the points discussed above is that the corner formula as now used probably would not be safe against corner cracking were it not for the fact that very seldom do the loads travel over the extreme corner, but actually travel, for the most part, at least a foot or more from the corner. The corner theory for the design of the slab, although not final, is the most acceptable theory we have at present and seems to be giving satisfactory results.

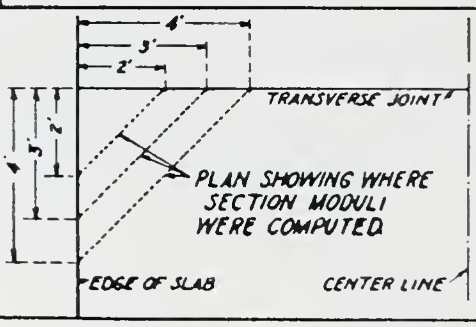
Study of Several Cross-Section Designs for Strength and Economy. It has already been stated that the strength of the corner depends in a large measure upon the actual thickness of cross-section at the corner, and this varies, depending upon the shape of cross-section of the slab finally adopted. In Fig. 17 is shown a study of the relative strengths of several cross-section designs on the basis of the calculated section modulus at the corner. Comparison is also made of the concrete required for these various designs. It will be seen that there is a very great difference in the edge strength, depending upon the design, and that with a given amount of concrete it is quite possible to obtain greatly different strengths. A complete study of this kind will show the best cross-section to use, considering both strength and economy. The section moduli were calculated for sections two, three, and four feet from the corner, measured along the edge of the pavement, for corner cracking ordinarily occurs within this zone.

REINFORCING STEEL

The subject of reinforcing steel for concrete highways is still in an unsettled condition. At the present time, a special investigation is under way in the field under the direction of the Highway Advisory Board of the National Research Council in an attempt to settle definitely the degree of benefit to be obtained from the use of steel. Theoretically, it can be shown that steel does add to the resistance to cracking of the concrete under load, provided it is so placed as to receive tensile stress. There is one point which is frequently over-

looked, however, in connection with the extra strength provided to roads by reinforcing steel. If it is assumed that the modulus of elasticity of steel and concrete are 30,000,000 and 3,000,000, respectively, and that the bond resistance of the steel reinforcing is unbroken; then if the concrete is stressed to 600 pounds per square inch, at which stress a crack ordinarily occurs, the steel is stressed to only 6000

STATE	CROSS-SECTIONS.	SECTION MODULI						CONCRETE PER MILE	
		2'	%	3'	%	4'	%	CU. YDS.	%
ILLINOIS		339	100	459	100	572	100	1858	100
INDIANA		277	82	416	91	554	97	2053	110
NEW YORK		277	82	410	89	538	94	1906	103
NORTH CAR.		340	100	507	110	657	115	2154	116
PENNA.		390	115	545	119	678	118	1955	105
A.A.S.H.O.		458	135	659	143	823	144	2112	114



U.S. BUREAU OF PUBLIC ROADS
DIVISION OF TESTS.

Fig. 17. Study of Section Modulus at Corner of Slab.

pounds. In reinforced-concrete building construction a stress in the steel of 16,000 to 18,000 pounds is permissible. It is thus seen that the full strength of the steel is incapable of being used for preventing the cracking of concrete highways. Because of the low unit stress possible in the steel at the point of failure of the concrete in tension, it is very readily apparent why the steel can not add very much to the

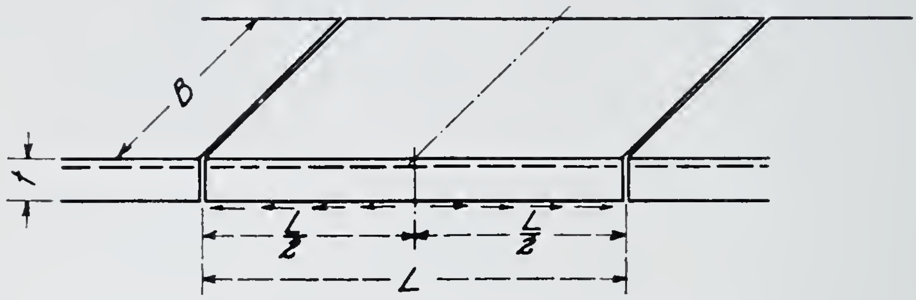
resisting moment of the concrete with the small amounts of steel ordinarily used in reinforced-concrete pavements. This is not an argument against the use of steel, for it is quite possible that, although the concrete might be cracked under loads, the steel will hold it together sufficiently to prevent further separation and no particular maintenance might be necessary.

Columbia Pike Experiments. In order to gain further light on the value of reinforcing steel an experimental road was constructed near Washington in the autumn of 1921.[6] This pavement was divided into a number of sections having many differences in detail design. These sections, in general, were not shorter than 200 feet in length, and were separated by transverse expansion joints. It will be impossible to consider this experiment in detail, but several of the sections are interesting because of their different behavior with different percentages of longitudinal reinforcing steel. In all cases the steel was placed with sufficient overlapping so that in effect it was continuous throughout the entire length of a 200-foot section. No attempt was made to break the bond. At the present time the following observations hold with regard to the appearance and behavior of the several sections.

In sections which have 8 to 14 deformed rods, ¾-inch round, placed longitudinally, transverse cracks occur at frequent intervals a very few feet apart. These cracks, however, are very fine and in some sections are barely discernible. Sections which have eight ¾-inch rods are not cracked as frequently as those having 14 of the ¾-inch rods. One section having four 1-inch rods is cracked slightly less than sections having eight ¾-inch rods. Sections which have reinforcing varying from four ¾-inch to four ½-inch rods are free from fine transverse cracks, but have wide open cracks, similar to those found in plain concrete sections, but spaced at greater distance (60 to 70 feet, as compared with 40 to 50 for plain concrete). Sections which are reinforced with 25 and 50 pounds of mesh per 100 square feet have no fine cracks, but do have open cracks spaced at greater distances than would ordinarily be found in plain concrete. In order to discover the cause for the action of these several sections, the cracks were opened in a number of instances, thus exposing the steel.

It was found that in those sections having eight or more ¾-inch deformed round bars no change in diameter of the bars had occurred.

In the section reinforced with four 1-inch bars, slight reductions in diameter were found. In the section having four ¾-inch bars, the diameter was reduced to ⅝ of an inch. In sections having eight ½-inch rods, the diameter had been reduced to approximately ⅜ of an inch, while in still another section having only four ½-inch bars, the bars had completely broken with a reduction in diameter to about ¼ of an inch. In sections reinforced with mesh to the extent of 25



Let L = Spacing of Transverse Joints.
a = Area of Steel.
B = Width of Pavement.
S = Allowable Tension in Concrete, S_1 in Steel.
f = Coefficient of Friction at Subgrade.
W = Weight of Concrete per Square Foot.
t = Thickness of Pavement.
E_s = Modulus of Elasticity of Steel. E_c of Concrete.

For Condition of no Cracking . $f\frac{L}{2}WB = B12tS + a\frac{E_s}{E_c}S$ -----(1)
For Condition of no Wide Cracking . $f\frac{L}{2}WB = aS_1$ -----------------(2)

Results shown in Table are obtained from above formulas, assuming
$S = 30$#p□" at 10-15 days
$\frac{E_s}{E_c} = 10$
$f = 2.0$ $t = 6''$
$W = 75$ $B = 18'$
$S_1 = 25000$

Amount of Longitudinal Steel	Required Spacing of Transverse Joints	
	For no Intermediate Crack	For no Wide Cracks
Plain Concrete	28.8	28.8
4-¾"□ = 1.76□" = a	29.2	32.6
8-¾"□ - 3.52□"	29.6	65.2
12-¾"□ - 5.28□"	30.0	97.8

Fig. 18. Spacing of Transverse Joints as Influenced by Longitudinal Steel.

and 50 pounds per 100 square feet, the mesh was completely broken at the cracks. From these sections it is strongly indicated:

1. That longitudinal steel up to a certain amount does increase the spacing of the transverse cracks and these cracks will open on contraction.

2. That longitudinal steel above this amount might produce fine transverse cracks, spaced in some cases only a few feet apart.

Influence of Steel on Spacing of Transverse Joints. It should be remembered that in the above sections the transverse joints were spaced 200 feet apart, and it is not to be inferred that the same behavior, with regard to cracking and breaking of the reinforcing steel, would be found with different spacing of transverse expansion joints. For instance, if the transverse joints are spaced closely enough together it would be quite possible for the combined strength of the concrete and steel in tension at the mid-section to overcome the total frictional resistance between that section and each transverse joint. In this case, notwithstanding conditions making for high contraction, the slab would slide over the subgrade with no failure at the center. The analysis in Fig. 18 should furnish means for adjusting the percentage of longitudinal reinforcing steel and the spacing of transverse joints in such a manner that no intermediate cracking, or at least no wide open cracking, is liable to occur. Apparently, the choice of the amount of steel must rest on the question of the economy resulting from its use. By using a large amount, the number of transverse joints may be decreased. If no joints are used, the number and width of cracks will vary, depending in part on the amount of longitudinal steel, and consequently the maintenance expense will vary. If the extra cost of the steel is compensated for by decreased yearly cost of the surfacing, the use of steel is economical. For the present no adequate data seem to be available on this point, and it is hoped that the present investigation of the Highway Advisory Board of the National Research Council will develop some useful information.

Allowance for Pavement Expansion. It has been pointed out that there are several influences which tend to change the length of a concrete pavement. They are:

1. Change in temperature.
2. Change in moisture content.

No doubt the pavement suffers from the combined influences of both of these agencies, and in order to consider the necessity for the provision for expansion of a concrete pavement we must first consider the effects separately. Let us first neglect temperature. It has been indicated that when the pavement dries out it shrinks because of moisture evaporation, under extreme conditions as much as 0.0005 of an inch per inch of length, or a distance of 0.6 of an inch per 100 feet. Perhaps under more normal conditions, because of the moisture

accumulated from the subgrade, the shrinkage factor is less than the above amount. So far as our tests have shown, it is doubtful if the concrete ever regains this shrinkage, even in times of wet weather, although it may very closely approach its original length, due to moisture, in the spring of the year.

Other experimenters, however, seem to believe that the concrete might actually grow in length due to the saturated condition. The expansion of concrete as we have measured it seems to amount to 0.0001 of an inch per inch of length—the equivalent of a little more than 0.1 of an inch per 100 feet—a negligible amount. So far as temperature is concerned, much depends upon the time of the year when the concrete is laid as to whether or not much allowance need be made for expansion. If the concrete is laid in cold weather, say 50 degrees F., there is the possibility of a temperature increase of perhaps 70 degrees, with a change in length of approximately 0.5 of an inch per 100 feet. If to this be added the moisture expansion in the spring of the year, a total expansion of 0.6 of an inch per 100 feet will take place. If it is desirable to eliminate direct compression in concrete from this cause it would seem necessary to provide for expansion of at least this amount; and, necessarily, if the joint-filling material is to remain effective as a moisture-excluding agent during times of shrinkage, the expansion joint would theoretically have to be wider than 0.6 of an inch. If, however, the concrete were laid in warmer weather, the allowance for expansion could be reduced. There is some question, of course, as to the economy resulting from the use of expansion joints. If no provision is made for expansion, the compressive stress produced in the concrete by an expansion of 0.6 of an inch per 100 feet is approximately 2000 pounds per square inch, and were it not for the fact that the concrete probably behaves in a somewhat plastic manner and thereby relieves this stress, more failures by blow-ups would occur than at present.

This much seems certain, unless provision is made for movement of the concrete, rather high direct stresses are apt to be produced in times of combined wet weather and high temperature. This fact is well illustrated by the many blow-ups occurring in the spring of the year. The neutralizing effect of drying out of moisture is also well illustrated by the fact that many blow-ups recede during the progress of the summer owing to the drying out of moisture from the pavement.

The Longitudinal Joint. It has been pointed out that under

equal temperatures at the edge and bottom of the slab, and unequal moisture content, both might lead to the curling up of the slab from the subgrade. Changes which occur in the subgrade itself, such as undue shrinkage at the sides or heaving at the center due to frost

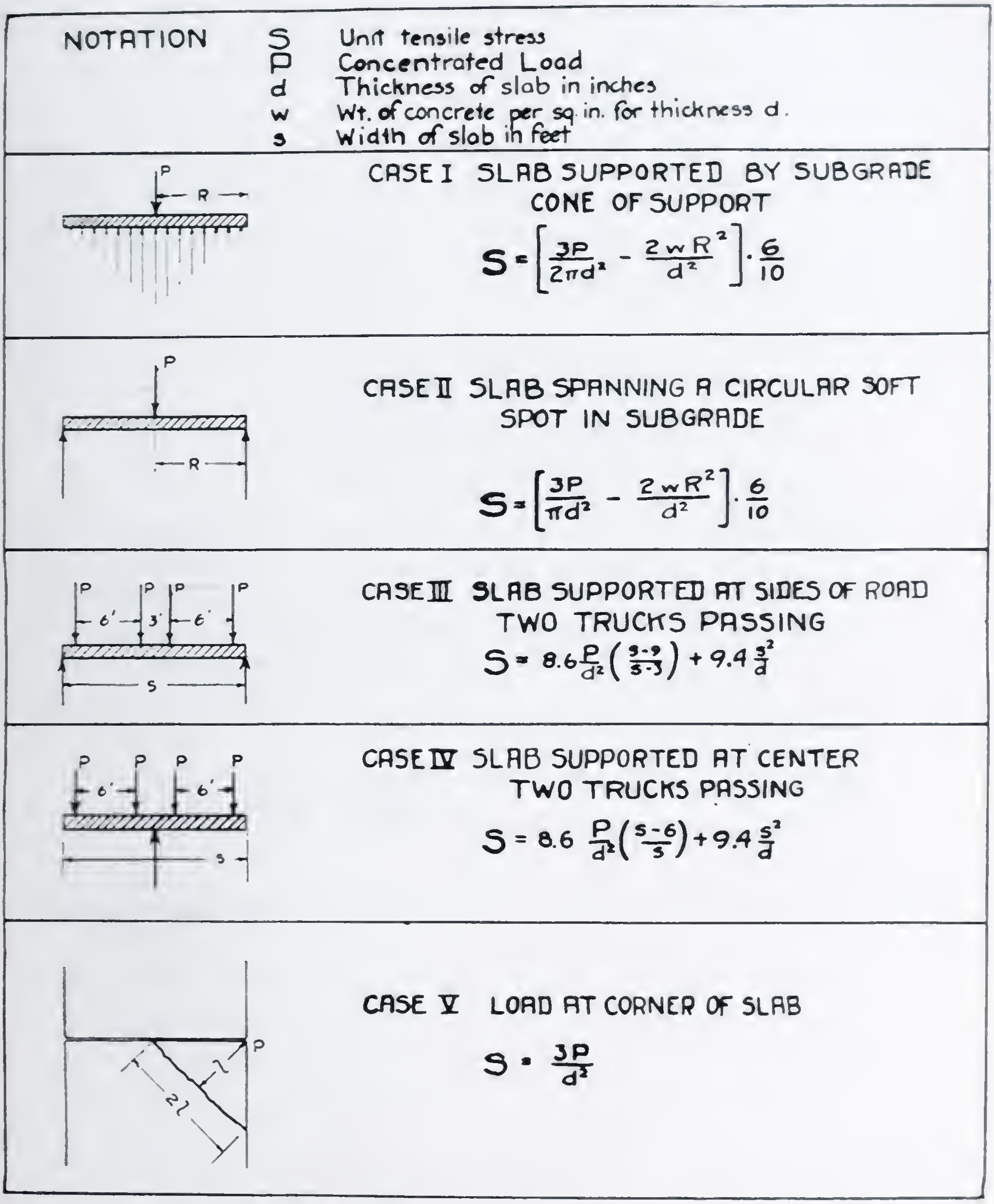
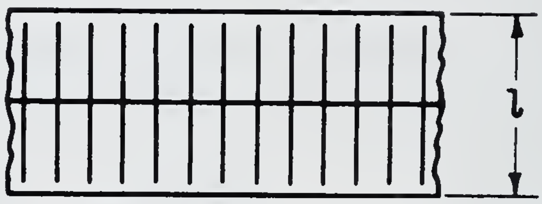


Fig. 19. Thickness of Slabs to Prevent Longitudinal Cracking.

action, might also lead to non-uniform support. It is quite evident that there are often conditions under which the pavement might have good support at the center, with very little at the edges, or the reverse might be true, and under these conditions heavy trucks passing one another will produce very high bending stress. The analysis in Fig. 19

gives two cases (Cases III and IV) of this sort. By substituting the proper values, it may be shown that the thickness of an 18-foot slab at the center which will just break under two passing five-ton trucks is approximately 12 inches.

From this calculation it is quite evident that it would be highly uneconomical to attempt to design a slab of full width of sufficient thickness to prevent longitudinal cracking where conditions exist such as bad subgrades or deep frost action making for high vertical movement. A longitudinal crack is to be avoided because of its tendency to form diagonal cracks extending to the edge of the pavement with the production of weak corners. This is prevented by the use of a



Let f = coef. of friction between slab and subgrade.
" s = unit stress in steel.
" a = area of steel per linear foot of road.
" w = weight of concrete slab per sq. ft.;
then, if all tension is carried by the steel,

$$as = wf\frac{l}{2}.$$

The maximum value for f = about 2.0
If l = 18' and thickness of road is 8".

$$a \times 25000 = 100 \times 2 \times \frac{18}{2}. \qquad a = \frac{1800}{25000} = 0.072 \,\square''$$

This equals 24# per 100.□'

Fig. 20. Transverse Steel to Prevent Spreading of Longitudinal Joint.

center longitudinal joint. When a center longitudinal joint is used, however, efficient means must be provided so that the load will be transferred across the joint, making it possible for each corner to support its share of the load. The use of tongue-and-groove construction has proved successful for this purpose. In the far West, heavy dowel construction is used because of the extremely large amount of vertical movement between the center and the sides of the road. It is desirable to prevent the center joint from spreading, and in Fig. 20 are shown calculations for the amount of steel necessary for this purpose. The bars should be embedded at least 40 times their diameter to insure sufficient bond.

WEAR RESISTANCE OF CONCRETE PAVEMENTS

The design of concrete pavements would not be complete without some mention of the wearing resistance to be expected from the concrete. It is felt that high strength of concrete is not the only property which is important, for the expansion and contraction due to moisture and drying out, and also the repeated action of the frost, are all factors to be contended with. Denseness of mix and low absorption are very much to be desired. It is also important that there be high resistance to wear, especially in localities where tire chains are used. Recently an elaborate test was completed by the Bureau of Public Roads at Arlington to study the effect of different aggregates on the wearing properties of concrete. These tests have been published in detail[7], but I wish to quote here the conclusions which have been reached. It is to be remembered that these conclusions deal entirely with the resistance of the concrete to abrasion:

"1. That the rate of wear of stone concrete is, in general, not affected by the coarse aggregate, provided the coarse aggregate is equal or superior to the mortar matrix in resistance to wear.

2. That excessive wear will result from the use of very soft stone as coarse aggregate even though used in conjunction with a mortar of satisfactory quality. From the results of these comparative tests, it would appear that stone with a percentage of wear over 7 should not be used in concrete road construction.

3. That gravel concrete, in general, is at least as satisfactory from the standpoint of wear as stone concrete.

4. That gravel consisting essentially of siliceous materials are superior as regards both the amount and uniformity of wear to those containing a preponderance of calcareous fragments.

5. That gravels consisting of rounded particles are as satisfactory from the standpoint of wear as those consisting either wholly or in part of angular or crushed fragments.

6. That small amounts of shale occurring in the coarse aggregate will cause both excessive and uneven wear.

7. That the modified abrasion test for gravel in its present form is not an indication of the wear-resisting properties of coarse aggregates. It is suggested that if the severe impact action of the steel balls were decreased, much more indicative results would be secured.

8. That blast furnace slags should prove satisfactory for use in concrete pavements, provided the proportion of light, porous slag is so controlled that the weight per cubic foot will be at least 70 pounds.

9. That the presence of large amounts of light, porous fragments in blast furnace slag will cause excessive wear.

10. That somewhat better results are secured by the use of the smaller sizes of slag.

11. That slag or stone screenings are, in general, unsatisfactory as substitutes for natural sand as fine aggregates in concrete road construction.

12. That the copper and lead smelter slags used in these tests would make satisfactory aggregates for concrete road construction from the standpoint of wear.

13. That coarse sands, other things being equal, show greater resistance to wear than fine sands.

14. That the so-called 'tensile-strength-ratio' test is no indication of the wear-resisting properties of concrete made with these sands.

15. That the Talbot-Jones wear test is not, in general, an indication of the wear which takes place under traffic.

16. That neither the crushing nor the transverse strength of concrete is a measure of its wear-resisting properties.

17. That the addition of hydrated lime in the proportion used in these tests does not affect the wear-resisting properties of concrete.

18. That so far as resistance to wear alone is concerned, increasing the cement content beyond a cement-sand ratio of 1:2 does not materially affect the concrete. Leaner mixes on the other hand show marked increase in wear.

19. That unusual precautions should be taken in using mine chats or other similar harsh-working materials, so as to increase workability to a maximum and thus make possible a smoother surface finish.

20. That, other things being equal, either an excessively dry or an excessively wet mix will show less resistance to wear than concrete of medium consistency.

CONCLUSION

In conclusion, it must be quite apparent that the methods now employed for the design of concrete pavements are not entirely rational, but at the same time a surprising advance has been made in our ideas on design within the past few fears through the application of intensive highway research. It is undoubtedly a fact that we can now design a pavement with almost entire certainty of its proving thoroughly capable of carrying the loads upon which the design was based. This was utterly impossible just a few years ago, and the gratifying feature of the more rational methods is that they result not only in stronger but also in much more economical pavements.

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DISCUSSION

Mr. W. B. Spellmire, *Chairman*:* We have certainly listened to a very enlightening discussion of highway construction. The importance of the subject is emphasized when we bear in mind that according to the last census we have something like 17,000,000 motor-driven vehicles traveling our highways in the United States, and the wear and tear on our highways is more severe than it has ever been before. The speaker referred also to the necessity for keeping in mind the necessities of future traffic. That is possibly more important than some of us actually realize. I have reason to believe that steps are being taken now by certain interests to bring about highway illumination at night so that we may travel just as conveniently at night as by daylight. We can imagine a condition of 50 to 75 per cent. increase in the wear on our roads when that comes about; and that is also tied in with the thought of serving the rural districts with electric current.

Mr. C. M. Reppert:† Mr. Goldbeck's paper is of great interest to engineers engaged in highway construction and is of particular interest to the engineers of the Department of Public Works of Allegheny County, many of whom are present this evening.

The Allegheny County road system includes nearly 500 miles of paved highways built and maintained by the county, the extent of the traffic carried being indicated by the fact that approximately 125,000 motor vehicles, including trucks, have been licensed in this county.

This county is now about to start an extensive program of road building under funds provided by a bond issue of 1924 under which it is expected that about 60 miles of additional improved roads will be provided, a number of dangerous curves eliminated, existing roads widened and reconstructed, and a number of grade crossings eliminated, at a total cost of more than $8,000,000. We realize that with the increase in road mileage and in the volume and weight of traffic the road problem is getting bigger every year.

In the road problem we are chiefly concerned with the question of permanence and cost of maintenance. Last year our Maintenance Department resurfaced about 42 miles of road, and this year the program embraces extensive repairs or additions to about 60 miles of road.

*Manager, General Electric Co., Pittsburgh.
†Assistant Director, Department of Public Works, Allegheny County, Pittsburgh.

The cost of maintenance of roads in this district may naturally be expected to be considerably higher than in other districts owing to the nature of the topography and soil conditions, and also for the reason that we are located in the center of a very extensive industrial and coal-mining district. During the past year the expenses chargeable to extraordinary maintenance in the removal of earth slides exceeded $250,000. From the foregoing it will be seen that we have a very live interest in technical matters relating to the design of roads.

We are very much interested in what Mr. Goldbeck has told us about the investigations and tests which have been conducted to determine the suitability of soils in the subgrade of roads. It is of great value to know that a test can be made to determine what should be done with a given subgrade condition. It would seem that, hitherto, undue dependence has been placed by designing engineers upon the strength of the road structure to carry the loads, and that variations in conditions have been taken care of chiefly by varying the thickness of the paving material. We have every reason to believe that subgrade conditions have a great deal to do with the failure of roads and the disintegration of materials. Soil conditions in this district are very bad, the soils being largely clay with little admixture of sand, thus having high absorption values and shrinking and swelling considerably under moisture conditions. We have come to the conclusion that not only must free water be prevented from affecting the subgrade, but that precaution must be taken in many cases to take care of moisture due to capillary attraction.

We are now building two reinforced concrete roads on clay subsoils upon a preliminary foundation of granular material. In one case we are using granulated slag, and in the other crushed slag, with the voids filled with fine material. The speaker would also refer to a somewhat similar subgrade treatment resorted to in 1921 in the building of a portion of the Boulevard of the Allies and in the improvement of Ravenna Street. In these cases the subgrade was what we term locally a clay quicksand—a very unstable material—and excellent results were obtained by laying these pavements on broken stone and crushed shale. The results have been so good with regard to the permanence of the pavement under adverse conditions that further use of such type of construction is indicated.

It must be realized that it is extremely difficult, owing to the very nature of the problem, to predict in advance of construction whether and to what extent preliminary treatment of the subgrade is necessary. The methods discussed by Mr. Goldbeck are applicable to scientific settlement of the problems involved, and should therefore be made the basis of future road designs.

In preparing specifications and making new designs for our roads, particularly concrete roads, we have had frequent occasion to refer to the results of scientific investigation which has been made by Mr. Goldbeck and others connected with the several state, federal, and university laboratories, and I would express our appreciation of the services of these men in making it possible for us to improve the serviceability and durability of our construction. The full possibilities to be attained by the careful design of a road have not been hitherto generally appreciated. As a very considerable portion of public funds is devoted to the construction and maintenance of roads there can be no question but that more attention must be given to their proper design and construction.

Mr. W. B. Spellmire, *Chairman*: I should like to ask Mr. Goldbeck if there are any other roads in the country similar in mixture to the sand and gravel and clay we find in New Jersey, particularly toward the seashore. Those roads carry a tremendous amount of travel and they seem to be maintained pretty well.

Mr. A. T. Goldbeck: You refer to the ordinary gravel road? A great many states have gravel roads and they stand up very well. There is a difficulty, however, that develops with gravel roads, and that is the formation of what are called rhythmic corrugations. Under our present high-speed traffic you get corrugations that are, on the average, spaced about 30 inches apart and about 1½ inches in height, and that means a constant dragging to keep those roads in passable shape. Calcium chlorid has been used with more or less success to prevent these corrugations from forming, and in some cases bituminous treatment has been used. One of the most successful methods has been to keep a layer of about one inch of loose, clean gravel constantly dragged over the surface. That means constant maintenance, and it becomes rather expensive to keep the surface in shape under more than about 1000 vehicles a day.

MR. L. P. BLUM:* The work of testing with reference to roads is a modern development and a development of increasing importance. There is just one thought that has occurred to me with reference to this and that should be emphasized more than any other. Although the results of elaborate tests have been published, many of our engineers are not using the results of those tests either in their specifications or in construction. For example, the speaker pointed out the necessity of securing a good, smooth subgrade; yet I believe it is safe to say that the majority of the roads are graded without the use of a subgrade templet or any other means of securing the accuracy in subgrade which all authorities agree upon as an essential.

When it comes to the finish of the road the same carelessness seems to be the predominating note in the construction. Too little attention is given to finishing the surface of a road as smoothly as possible. These are practical matters which construction engineers can not afford to ignore. Specifically, no road can be thoroughly and properly graded without a subgrade tester, and no road can be finished properly and smoothly without templets and finishing equipment to obtain the smoothest possible surface, both transversely and longitudinally.

MR. A. E. ANDERSON:† I should like to ask the speaker one or two questions. I gather from his remarks, as well as my own reading, that the evil genius of the roadway or highway is capillarity. That depends upon porosity. Is there any figure or any test to determine the line between the porosity that maintains capillarity and the porosity that allows the moisture to go into free water, and how is that affected by the manner in which the subgrade is tamped?

In the rush of the last ten years we forget that the first self-propelled vehicle was the tractor which dragged the threshing machine over the clay roads, and the difficulty was with the bridges designed to carry nothing heavier than a load of hay, so that when the steam engine got onto that bridge it went into the creek. That is similar to the condition we have in Allegheny County to-day with our heavy trucks going on a road designed for light traffic. In the Schenley Farms district, within two weeks, the people were up in arms because the trucks hauling from the excavation for the University of Pitts-

*Blum, Weldin & Co., Pittsburgh.
†Attorney, Pittsburgh.

burgh stadium had caused such havoc with the pavement that the streets were practically impassable. Aside from that, the streets would have been sufficient for 25 to 40 years ordinary wear. It may be necessary to follow the practice of the railroads, where the main line is maintained at a standard which will carry any weight of car or locomotive that may come over the road.

MR. W. B. SPELLMIRE, *Chairman*: That same principle was recognized by the telephone company when they put in a telephone which could be used not only to talk across the street, but across the continent.

MR. A. T. GOLDBECK: As to the question of capillarity, that is pretty well taken care of by the "moisture equivalent" value of 20 per cent. Soils that are above that figure are verging into the plastic type of soil. We have no results of tests to measure what you have in mind except the moisture-equivalent test.

As to the tamping and this matter of capillarity, there are certain types of road that are drier than others merely because of their type. A gravel road, for instance, should dry out very rapidly. It is reasonable to suppose that the water under that road would be less than if the surface had been impervious. With concrete roads, which are practically air-tight, the subgrade under the road will be moist, and that is simply due to capillarity, but I did not mean to say in the paper that capillarity is all-important. I think I expressed the opinion that free water was the most important kind to look out for, and it is especially important to provide drainage to prevent free water from reaching the slab.

As to the design of highways, there are thousands and thousands of miles of highways carrying perhaps a couple of vehicles a day, and light ones at that. Contrast that with Allegheny County. If we adopt the policy of improving all roads to stand the heavy traffic that they might possibly get in the future we would not have money enough in the country to afford it. The most economical way is to design the roads for the traffic they are likely to get at some time in the immediate future. If you do more than that you do more than is necessary. When the road does get heavy traffic then is the time to strengthen it. The traffic censuses I have seen show that the heavy trucks do not go very far away from centers of population excepting in

certain districts. Light trucks go farther, and lighter ones still farther. Therefore as we go from the centers of population the lighter the roads can be. And that is the economical way of financing the highways at the present time. Build strong enough for the near future, and when the time comes for improvement make them better.

If we could establish the idea that these heavy loads should be carried on more than four wheels we could save ourselves trouble. When they increased the size of locomotives they put more wheels under them. We have at the present time developed six-wheel trucks in California, and in Philadelphia we have the six-wheel bus. I believe that is logical. In that way you can carry a big gross load with correspondingly low wheel-loads, and it is the heavy wheel-load that does the damage.

MR. A. E. ANDERSON: You did not touch on the width of the road.

MR. A. T. GOLDBECK: We recently made an investigation in which a man went out and put one-foot marks on the pavements of different widths in different locations and those marks extended clear across the pavement. The observer went out frequently enough to get an idea of the average position of the trucks. We have come to the conclusion that as far as two-way traffic is concerned an 18-foot road is wide enough to accommodate both trucks and automobile traffic. There seems to be ample clearance. The observations show that the trucks, in general, hang closer to the sides of the road than the automobiles, I suppose because the drivers are in less danger of going over the side of the road than with the high-speed automobiles. Then another thing, the motor truck does not want to be in position to turn out every time an automobile comes past. The fact that the heavy motor truck stays closer to the side of the road provides more clearance than would otherwise be the case. The 18-foot road seems to be all right for two-way traffic. High density of traffic, of course, might require a wider roadway.

MR. N. F. HOPKINS:* In the state of Ohio there is a rule to limit the weight of the trucks on the road during March and April.

*Harrop & Hopkins, Pittsburgh.

That is when the frost is going out of the ground and subgrades are in the worst possible condition.

The author spoke of a sand-clay mixture as sometimes being desirable as a foundation. In this vicinity we have an excellent material for that purpose in granulated slag which might be harrowed into or rolled on top of the subgrade. Granulated slag with the proper amount of water rolls into a tough compact mass that hardens with age and makes an excellent foundation for brick pavement. We have laid thousands of square yards of brick pavement with granulated-slag base and consider that 12 inches of granulated slag is as good as five inches of concrete.

MR. F. C. SCHATZ:* My thoughts run along the other side of the paper presented by Mr. Goldbeck; that is, the wide use of roads—not the building of them. I wish we could thoroughly impress upon the people of our community the value of improved roads and their importance to us, both commercially and socially. Perhaps they are of most importance to us commercially. However, as an adjunct to our social life, they are also important. People from many other cities (such as cities located on waterfronts) who come to Pittsburgh to live are often unfavorably impressed at first, but once they get out into the country and become acquainted with the beautiful scenery they soon become enthused and are boosters for our city. We have in Western Pennsylvania some of the most beautiful spots to be found anywhere, and I am happy in the thought that we are going to be able to reach more of these beauty spots in Allegheny County because of the additional territory that will be opened up and be made accessible by the improved roads that are soon to be built.

Another thought has been running through my mind as I listened to the speaker this evening; that is, the importance to the taxpayer of building roads more scientifically and more durably. The type of roads that we have in Allegheny County now is not, of course, the equal of the new type of roads being built to-day and, while a great many of the old roads will have to be rebuilt in time, I do not believe that Allegheny County has sustained any financial loss because of them. They did not cost near as much per mile to build as present-day roads, and we still have certain assets in these roads by reason of

*Assistant Manager, Joseph Horne Co., Pittsburgh.

the grading and foundations. However, now that we are in an era of high costs of labor and materials, we should build with a view of making the life of the roads commensurate with the larger investment. I think these problems are being approached in a very able manner by our County Commissioners and the men at the head of our Department of Public Works, who, before spending large sums of money for roads, are endeavoring to get all the technical information possible on the subject. I do not recall any administration in Allegheny County that has tackled the expenditure of large sums of money in as enlightened and scientific manner as the present administration—from the County Commissioners down. I do not know that I need to say anything in the way of sounding their praises, but, while I am on my feet and, as it were, thinking out loud, I feel moved to say it, and for that reason I am pleased that you called on me to say a few words.

MR. W. A. WELDIN:* It seems to me there is a little distinction that might be made here. According to the analysis of stresses in the concrete road slab, which Mr. Goldbeck has so clearly shown here, one heavy truck passing over such a structure, not designed for such a load, would crack it, and the weather would do the rest. In other words, the design of the concrete slab is properly based on the maximum wheel-load quite regardless of density or amount of traffic.

I should think that for light traffic the gravel type of road or other cheap construction would be economical because the maintenance cost, being a function of the density of traffic, would be small. But once we go to the rigid type, such as concrete, we should "go the limit" and design for the maximum load.

MR. P. J. FREEMAN:† I do not think I have very much to add to the discussion. I think we are indebted to Mr. Goldbeck for the talk he has given to-night. We are endeavoring to follow out some of the recommendations of the United States Bureau of Public Roads and the other organizations mentioned, using the results of those various tests to the best of our ability in connection with our road program which we have under way for 1925. We have a laboratory and we are studying subgrade conditions, which we believe to be of very great importance.

*Blum, Weldin & Co., Pittsburgh.
†Chief Engineer, Tests and Specifications, Allegheny County, Pittsburgh.

Mr. S. W. Jackson:* Mr. Goldbeck has brought out several points which throw much new light on the question of underdrainage. Our young engineers are apt to pay too little attention to this matter. Wih more experience, the importance of the subject is realized, and it may be carried to the other extreme and an attempt made to cure all drainage conditions by the use of underdrains. I think it has been the experience of the state Highway Department that we have probably wasted more money in placing drain tile that was not necessary than in any other feature of our work, and I believe this is true also in county road-building departments. Where there is free water, as has been pointed out, drain tile or stone drains should be used; but we can not depend upon preventing capillary attraction, where the moisture is drawn up and held close to the bottom of the pavement, by the use of drain tile. As Mr. Goldbeck has pointed out, if we add coarse material such as sand, cinders, or granulated slag, we may improve the condition of many subgrades. We may stabilize the subgrade materially, and this in itself is equivalent to increasing the thickness of the pavement.

The one predominating by-product of Allegheny County is slag. We have thousands of tons of granulated slag going to waste every day and there is ample opportunity in this vicinity to take advantage of this by-product and see that it is used to better advanage than it has been in the past. I am pleased to note that the County Department of Public Works is making tests along this line.

Major J. P. Leaf:† I am glad to have heard the paper and to see so many road men here. I am still of the opinion that we must limit the weight of trucks going over the road. I think the state highways of Pennsylvania to-day are among the best roads built, but we have not made any roads yet that will withstand the very heavy trucks that go over the roads. From my experience as an engineer, using almost all the materials that have been used, I do not believe there is anything that will withstand 13-ton traffic. We have not been able to do it in the roads we have built. I do not see any sense of one man building a road and some other fellow ruining it. If one man owned the road and maintained it and owned the truck that went over it, there never would be a 13-ton truck on the road—I am sure of that.

*Division Engineer, Pennsylvania Department of Highways, Pittsburgh.
†Beaver County Commissioner and Consulting Engineer, Rochester, Pa.

When street-cars first came into existence they did not begin to weigh 13 tons, yet they had to go on steel rails. Those steel rails did not last 30 years, and we all expect the life of pavements to equal that of the bonds that built them.

On the matter of concrete roads, I do not know whether I am a pessimist or not, but I think we have allowed too much sulphur or sulphate of lime to be put into our cement. We have in this vicinity a good many strata of stone of very fine quality. In the course of ten or fifteen years they disintegrate because they have a very small amount of sulphur. Yet we turn around and build roads of cement that has in it carloads of gypsum that will ruin the work as sure as you are a foot high.

I was very much pleased to hear the discussion on the subgrade. I have always maintained that if we could use some sort of subgrade under concrete roads we would greatly increase their life. We have had the experience of putting tar on top of a dirt road and getting a pretty good road. The main reason for that is that it keeps the water out of the subgrade.

Another fine thing about this country is the water. I was in Texas a while ago and they told me they had not had rain for eight months. They put a layer of tar on top of gravel and it looked like our concrete base with asphalt top. But they did not have fifteen or twenty tons of steel going over it. I like the idea of putting another set of wheels under the truck to distribute the weight.

Mr. Winters Haydock:* The present big problem confronting highway builders, whether state, county or federal, is to supply the enormous mileage of hard-surfaced roads which the country is now demanding. The demand is now for mileage, not for width; therefore, in general, we can build only roads wide enough for one lane of movement in each direction. How soon does the speaker of the evening think the big problem facing the road builders will be the problem of increasing the capacity of our over-congested highways and supplying the country with four-lane roads where the rapidly increasing traffic has made the present two-lane roads inadequate?

Mr. A. T. Goldbeck: I have seen a prediction of the increase in the number of motor vehicles, and my recollection is that the pre-

*Chief Engineer, Bureau of Traffic Relief, City of Pittsburgh, Pittsburgh.

diction is in ten years there will be 30,000,000. That is going to put a lot more motor vehicles on the road. I think, however, that it will be a long time before we will have four-way traffic roads except in terminal areas. It all depends on the density of traffic. The need for four-way traffic roads is manifest right now in many places. There is much discussion at the present time as to whether it is better to build a wide road or two narrow roads. I do not think I am competent to answer that question.

Mr. N. F. Hopkins: Does the four-way traffic road carry as much traffic as two two-way traffic roads?

Mr. A. T. Goldbeck: I am inclined to think that two two-way, two-lane traffic roads would carry more traffic than a single four-lane traffic road.

Mr. Winters Haydock: I believe I would differ with the speaker on that point. On a road having two lanes of traffic—that is, only one lane in each direction—the rate of travel is set by the slow vehicle at the head of the procession, and where the traffic is heavy there is no chance for the drivers of faster vehicles to pass that slow vehicle without taking chances and endangering themselves and other users of the highway. The rate of speed and the capacity of the road are therefore limited by the slowest vehicles. On the other hand, with a four-lane road—that is, a road having two lanes in each direction—the faster vehicles can weave in and out from one to the other of two lanes and so pass the slower vehicles without danger, and thereby greatly increase the capacity of the highway.

Mr. John A. Ferguson:* One of the earlier speakers this evening remarked about the quantity of gypsum added to the cement clinker as a factor in the uniformity of the quality of cements. In view of the fact that the casual observer may feel from this that detrimental amounts of gypsum are being (or may occasionally be) added to cement, your attention is called to the fact that the current specifications of the American Society for Testing Materials permits not to exceed two per cent. by weight of the cement to be the sulphuric anhydrid (SO_3), and, at the same time, permits five per cent. to be

*Consulting Engineer, Pittsburgh.

magnesium oxid. Two per cent. of sulphuric anhydrid means that the amount of gypsum used in the manufacture of the cement does not far exceed three per cent. by weight of the cement, while a far more harmful substance (magnesium oxid), if used to excess, may be present up to five per cent.

Much more variation in the quality of cement may result from the extent of burning of the clinker. Still more variation in the strength and quality of concrete may be (and constantly is) introduced in the size, grading, and quality of aggregates. Amounts of water used in the concrete in proportion to the amount of cement present have the greatest effect of all the conditions surrounding the manufacture of the finished product—cement concrete in place in the structure. Enough is known of the effect of batch placing of the wet concrete mass upon the strength of structural units or mass concrete, and the variations in strength of the different batches and even between the different bucketfuls of concrete deposited in place, to warrant the conclusion that more interest is needed in the manufacture of the finished product, concrete, than in the manufacture of the finished product, cement.

In connection with a bridge which was disintegrating, recent chemical analysis of the concrete, of the efflorescence on the concrete, and of the amount of deleterious materials in the concrete, it was found that the sulphuric anhydrid (SO_3) was present in varying amounts. This could have come from the sand, gravel, or ground water, which was running over the roadway of the structure. The general conclusion was drawn that too liberal use of mixing water would most likely result in imperfectly set cement that would thus be likely to be soluble in the ground water, especially if it contained mild amounts of SO_3.

Mr. A. T. Goldbeck: I should like to ask whether in connection with this investigation you made determinations on the kind of soluble matter in different kinds of cement?

Mr. John A. Ferguson: No, just the one in question.

Mr. A. T. Goldbeck: I gather that you came to some kind of conclusion as to the durability of cement, depending on the chemical analysis or some other kind of test?

MR. JOHN A. FERGUSON: We just drew the one conclusion, that the presence of SO_3 seemed to be traceable to the ground water seeping through porous or imperfectly set sections of concrete; and that either the ground water contained an excess of SO_3 from adjacent blast-furnaces or that this SO_3 came to the structure in the sand or gravel.

I believe that density of concrete is as important as structural strength, and that its permanence depends upon the permanence of cement compounds, which are not permanent when exposed to the weather if the gel in the cement is soluble.

MR. C. H. LOVEJOY:* I was interested in what one of the gentlemen had to say about these tests being made and nobody paying any attention to the results. I have been in Arkansas for the last two years. Up here you are interested in every new thing and you have facilities for keeping in touch with what is going on. Down there the Bureau of Public Roads is not always popular. The government is helping finance most of the roads and will not produce the money unless the construction is carried on in just the right way. They are building a number of roads across gumbo soil. That is a sticky clay somewhat like the adobe mentioned by the speaker. They are now using several inches of sand under the concrete in these cases. Where they did not do that the roads cracked badly and are terribly warped. Now they are profiting by this experience because the government is there to see that these results are put into effect, and this is now generally appreciated by the taxpayers.

*Highway Engineer, Pittsburgh Testing Laboratory, Pittsburgh.

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the William Penn Hotel, Tuesday, May 19, at 4:40 P. M., President W. B. Spellmire presiding, Messrs. Fohl, Goodspeed, Weldin, Dornbush, Affelder, Clark and Rankin being present.

The minutes of the last meeting, held April 21, were approved without reading.

Applications for membership from the following gentlemen, having been published to the Society, were elected to membership:

MEMBERS

Borg, John Edward
Chartener, Victor, Jr.
Dorsey, Charles H.
Lynn, Frederick Edward
Sherratt, Gayle F.
Williams, J. P., Jr.
Wyrouth, Clement J.

ASSOCIATE MEMBERS

Bernstein, Lester
Eckels, Samuel
Middleton, Raymond T.
Haertlein, Albert
Barrett, Cecil Hewins

Applications for membership were received from the following gentlemen and their names ordered published to the Society. Assignment to the various grades was as follows:

MEMBERS

Lougee, Lewis Omer
Raub, Edward S.
Wahl, Richard A.
Whiter, E. T.

ASSOCIATE MEMBERS

Gens, Clarence H.
Jones, John Lucien
Lane, Granville B.
Woolfolk, Arthur P.

JUNIOR

Donald, John S.

Request for reinstatement was received from Mr. David F. Boyd and, after discussion, it was moved and carried that he be reinstated to membership, the Secretary to notify him accordingly.

Applications for transfer were received from the following gentlemen and they were transferred to the grade of member:

Klages, George H.
Lauer, Willard Wood
Stevens, Frank Alex

The Secretary reported the death of the following members:

George Mesta ....Joined March, 1888—Died April 22, 1925
Klaus Sollie ......Joined December, 1920—Died April 19, 1925

The reports of the Secretary showing the financial condition of the Society at the close of business March 31 and April 30, having been audited by the Finance Committee, were approved.

In the absence of Mr. Clifford, Chairman of the Entertainment Committee, the Secretary reported that arrangements were about completed for the

Inspection Trip to Buffalo and Niagara Falls on May 23 and 24 and, from the returns received, the committee estimate that we will have between 50 to 75 in attendance.

In the absence of Mr. Leland, Chairman of the House Committee, the Secretary reported an evening attendance for the month of April of 386. The Chess Tournament was won by Mr. Dym.

Mr. Affelder, Chairman of the Membership Committee, stated that one meeting of the committee had been held to go over applications received since the last meeting of the Board and make assignment to the various grades of membership; also to act upon any reinstatements and resignations received.

Mr. Affelder stated that the committee had two names they wished to recommend to the Board of Direction for engraved invitations:

Mr. T. M. Dodson, Vice President, Pittsburgh Coal Company;

Mr. W. G. Warden, Chairman, Pittsburgh Coal Company.

It was moved and carried that the Secretary be instructed to mail invitations to these gentlemen.

The Secretary presented two letters from Mr. W. A. Weldin, who represents this Society on the Better Traffic Committee appointed by Mayor Magee. After discussion, it was moved and carried that a vote of thanks be extended to Mr. Weldin for the report and the work he has done on this committee.

It was further suggested that any recommendations any of the Board might have for Mr. Weldin be forwarded direct to him.

On motion, the meeting adjourned at 5:25 P. M.

K. F. Treschow, *Secretary.*

CIVIL SECTION

The regular bi-monthly meeting of the Civil Section was held in the Blue Room, William Penn Hotel, Tuesday, May 5, at 8:30 P. M., Chairman C. C. Dornbush presiding, 37 members and visitors being present.

The minutes of the last meeting, held March 3, were read and approved.

No further business coming before the Section, the paper of the evening was presented by Mr. Frederic Bigger, Architect and Town Planner, Pittsburgh, Pa., on "One Measure of Permanent Relief of Traffic Congestion in the Downtown District—an Inter-District Traffic Circuit."

The ensuing discussion was participated in by: C. C. Dornbush, Asst. Struct. Sales Engr., Jones & Laughlin Steel Corp.; George S. Davison, Pres., Gulf Refining Co.; Morris Knowles, Pres. & Chf. Engr., Morris Knowles, Inc.; C. N. Haggart, Structural Engineer; Louis P. Blum, Blum, Weldin & Co.; and the author.

On motion, duly seconded and carried, a vote of thanks was extended to Mr. Bigger for his very interesting paper.

On motion, the meeting adjourned at 10:06 P. M.

K. F. Treschow, *Secretary.*

THE WITHDRAWAL OF WATER FROM LAKE MICHIGAN BY THE SANITARY DISTRICT OF CHICAGO, AND THE CONSEQUENT LAKE LOWERING CONTROVERSY*

By Morris Knowles†

INTRODUCTION

General. There are three prime reasons for the discussion of this subject before the various branches of the engineering profession: (1) the general public interest which has been aroused, not only in the lake region, but also nationally and internationally; (2) it is one of the largest and most important engineering undertakings now before the American public; (3) the subject has a direct and important interest to Pittsburgh and Western Pennsylvania.

The popular idea is that Chicago, by diverting a large volume of water from Lake Michigan, has lowered the lake levels, with consequent damage to navigation, harbors, power, and water-supply interests in general. The solution offered by the propagandists against this diversion is that Chicago should purify its sewage and otherwise protect its water-supply. This sounds simple indeed, but the engineering and economic aspects are stupendous, and the solution of any problem of this size can not be undertaken from the point of view of one district or one interest alone.

Closely allied with such problem, which vitally affects the health of the entire Chicago district, are a number of other factors, which may be stated briefly to include:

1. The effect of the diluted Chicago sewage as to offensiveness to the people in the Illinois valley.
2. The effect upon floods in the Illinois valley.
3. The effect of low-water stages of the Great Lakes on shipping and lake ports.
4. The reduction in the ultimate water-power available at Niagara and on the St. Lawrence.
5. The development of the so-called "Lakes-to-the-Gulf Waterway."
6. The development of the "St. Lawrence-to-the-Ocean Waterway."

*Presented May 18, 1925. Received for publication June 23, 1925.
†President, Morris Knowles, Inc., Pittsburgh.

Because of the grave importance of all of these factors to the ultimate economic development of the Chicago Sanitary District; because this district has already expended $125,000,000 on sewage dilution and purification systems; because it faces a present construction program of an equal amount, together with over $35,000,000 on still further purification, making a total of about $300,000,000, the Sanitary District caused to be formed an Engineering Board of Review, to study and investigate the factors underlying the whole problem and to recommend remedial measures. This board consisted of 28 engineers coming from various sections of the United States. It was the privilege of the writer to serve as a member of this board and to act as chairman of the Committee on Reasonable Construction Program.

The report of this board was made in two parts—its recommendations were set forth under date of December 20, 1924; and Part 2, "The Technical Bases for the Recommendations of the Board of Review," was issued under date of January 23, 1925.

It is not the purpose of this paper to review the work of this Board, but merely to give a bird's-eye view of the broad engineering aspects of this great problem, because of its interest to the profession as a whole, regardless of whether one's special interest is in hydraulic or sanitary lines—in health, power, or transportation. Like other great undertakings—such as the irrigation projects of the West, the Panama Canal, and the water-supplies of New York, Los Angeles, and San Francisco—this work, involving, as it will, almost three hundred million dollars at Chicago alone, will be followed as one of the large engineering projects of modern times.

*Geological History of Region.** In considering the Great Lakes as they are to-day, and to understand their peculiar present geography, one should keep in mind the development of this region during the glacial and preglacial periods.

There is good evidence that the northern part of North America has been covered by at least five great ice sheets. The last one of these glaciers, known as the "Wisconsin Ice Sheet," extended as far south as what is now Illinois, Indiana and Pennsylvania. The melt-

*The data contained in this section are from "College text-book of geology," by T. C. Chamberlin and R. D. Salisbury. 1909. Holt, New York; "A naturalist in the Great Lakes Region," by E. R. Downing. 1922. University of Chicago Press, Chicago; and "Earth features and their meaning," by W. H. Hobbs. 1912. Macmillan, New York. The main features to which reference is made are shown in Fig. 1 and 2.

ing and receding of this ice sheet began probably between 20,000 and 80,000 years ago. It is impossible to be certain of the topography of the country around the Great Lakes region before the changes made by this glacier; but from the study of the general lay of the rock strata and their nature, the evidence of the rock hilltops that crop out of the glacial deposits, and from well borings, it is judged that the old valley, now occupied by Lake Michigan, extended past the present site of Chicago to the rugged hill country through which flowed a part of the glacial river system. It was probably a well-drained region with branched rivers flowing in deeply cut valleys between rounded hills.

It is stated that as the glacier melted and receded, the resultant waters were impounded at certain places between the front of the glacier and the terminal moraine, thus forming lakes. These three lakes have been named Chicago, Saginaw, and Maumee. All discharged to the Mississippi River. As the glacier continued to recede, the lakes increased in size until the large lake called Warren was formed. It is evident that toward the close of the Lake Warren stage a profound change was imminent—a diverting of some of the glacial waters away from their course to the Mississippi River and the Gulf of Mexico to the trench which crosses New York State and enters the Atlantic. As soon as the ice front had retired sufficiently to lay bare the bed of the Mohawk valley an outlet was formed and some of the water continued down the Hudson valley to the sea. This development is shown in Fig. 1 and 2.

It appears that the elevation of the water surfaces of the Great Lakes, during this period, was considerably higher than the present lake levels. This is evinced by the plainly marked beaches formed by the shore line of the early lake. For a long time Lake Chicago stood at a level about 60 feet higher than the present normal water surface. Later, the level dropped to a stage probably lower than the present lake surface. This was probably due to the retreating of the ice, thus uncovering some outlet to the north at a considerably lower level than the Chicago outlet. The lake rose again, as possibly the glacier advanced temporarily and again covered the northern outlet. It then assumed a level about 35 to 40 feet above the present elevation, and again found an outlet down the Des Plaines valley Evidence shows that Lake Chicago later assumed a new level at about 20 feet above the present water surface.

This fluctuation in the lake level was undoubtedly due in part to an uplift and tilting of the earth's crust. It is quite possible that the removal of the ice blanket brought from the earth a relatively quick response in uplift. This may have begun before the ice front had retired across the present international boundary of the United States. This uplift continued until the final disappearance of the ice. A far slower elevation of a somewhat different nature has continued even to the present day. Interpreting the records left by the ancient water

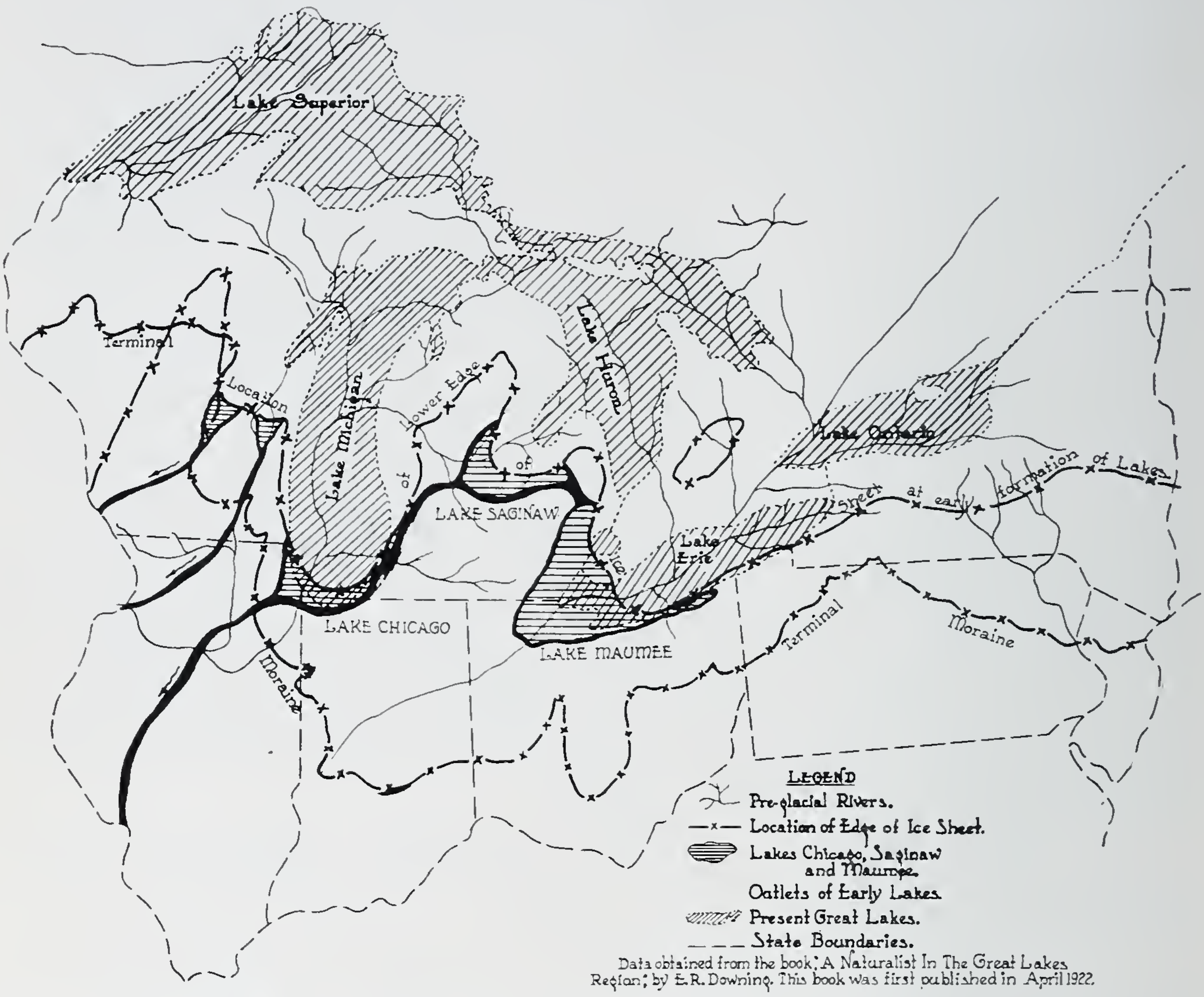

Fig. 1. Progressive Development of Great Lakes by Recession of Wisconsin Ice Sheet (Early Period).

planes of the Great Lakes, it was the uptilt of the land to the northward which brought the glacial lake history to an end and began the present system of the St. Lawrence drainage.

Dr. G. K. Gilbert, formerly of the United States Geological Survey, carried out an elaborate study upon the gage records preserved at the various gaging stations about the Great Lakes. Upon the basis of these studies, he concluded that the uplift is in the simple manner of a trap-door, the hinges of which lie to the southwest of Chicago.

location. No doubt the site now occupied by Chicago was a meeting place of early Indian traders and was visited by early travelers, who left no record of their explorations. However, the recorded incidents of the early development of the lake regions would indicate that there was some form of waterway from Lake Michigan to the Gulf of Mexico, through the Chicago portage.

It is generally conceded that the first of these early explorers to enter the region of the southern end of Lake Michigan was La Salle, who, about 1671, worked his way through the Chicago and Illinois rivers to the Mississippi. In 1673, Joliet and Marquette, with five companions, passed down the Chicago and Des Plaines rivers and recorded that they made the trip without taking their boat out of the water. In 1721, Father Charlevoix walked down the Kankakee in order to get to the Mississippi, because he had been advised that there was not enough water in the Des Plaines River to float a canoe.

Coming to the nineteenth century, Ebenezer Childs passed up the Illinois and Des Plaines rivers to Chicago in a small canoe, in 1821. Two years later (1823) Lieutenant Hopson, an officer at Fort Dearborn crossed the portage with ease in a boat loaded with flour and lead.

Early Plans for a Waterway from the Great Lakes to the Mississippi. The plan of reopening Lake Michigan's prehistoric southern outlet by constructing a ship canal connecting it with the Illinois and Mississippi rivers is not of recent origin. It was suggested first by the French explorers, Louis Joliet and Père Marquette, as early as 1673. The United States had such a canal under consideration as early as 1808; and, in 1822, when the British government gave definite expression of its attitude, denying American citizens the right to navigate the St. Lawrence River, the Congress of the United States passed an act authorizing the State of Illinois to build this canal. In 1827, Congress authorized the land grant to the state of Illinois for its construction. The canal was begun in 1836 and was known as the Illinois and Michigan Canal. It was completed in 1848, at a cost to the state of Illinois of more than $6,000,000. It was 6 feet deep, 40 feet wide at the bottom, and 97 miles long. It was fed in part by gravity flow from the Calumet River and partly by water pumped from the South branch of the Chicago River at Bridgeport. These two sources constituted a withdrawal of water from Lake Michigan of about 300 cubic feet per second.

This early navigation canal was built originally upon the shallow cut plan and did not, at first, take water from Lake Michigan through the Chicago River by gravity. With the increasing nuisance in the river, repeated recommendations for the enlargement of the canal were made (many by the United States Engineers), but it was not until 1865 that an act authorizing the city of Chicago to deepen this canal was passed. This deepening was made principally by cutting down the summit of the canal, so as to provide for gravity flow from the Chicago River. It was completed in 1871 at a cost to the city of Chicago of about $3,000,000 and produced a flow of nearly 700 cubic feet per second. Because the direction of flow of the canal was lakeward, at times for a period as long as 30 days in a year, while at other times the canal was stagnant for as long as 10 days, the pumping plant was rebuilt, with a capacity of 1000 cubic feet per second, and put in operation in 1884.

It is interesting to conjecture what would have been the attitude of the objector to the withdrawal of present amounts of water at Chicago if the new canal, now the subject of discussion, had been constructed on the line of the old Illinois and Michigan Canal (or practically an enlargement thereof) when one considers that water used in it was withdrawn from Lake Michigan with full acquiescence of the United States authorities.

Chicago's Development. At the time of the beginning of the Illinois and Michigan Canal, Chicago could not have been much of a metropolis. In the opening chapter of her story on the life of Judge Gary,* Miss Ida M. Tarbell says of Chicago in 1831:

"The town was not much to see in those days. Twenty to thirty log farmhouses scattered westward from the mouth of a river over a low and swampy prairie; a bare log church in which in turn three or four denominations worshipped; several rough boarding houses, frequently called hotels; five or six general stores and a post office, just opened to receive and care for the mails which were brought in on horseback once a week from the East, now and then from the South, and for which the settlers came from a hundred miles or more in every direction.

But if the new town was rough and unkempt it was bursting with life—the feel of its future was upon it. Traders, explorers, settlers, government agents, filled not only all the beds of the new town but the floors of its houses, night after night. Schooners were already coming from Buffalo and Cleveland and Detroit. There was talk of the government improving the harbor—

*McClure's Magazine, n. s. v. 1, May 1925, p. 9.

of canals and railroads from the East to the West. The town was lifted, too, from the ordinary commonplace of a pioneer settlement by Fort Dearborn and the government agency—well-cared-for places, with gardens and trees, kept up as befitted government possessions even if far from civilization."

During the period from 1850 to 1885 Chicago experienced phenomenal growth. From a population of about 30,000 in 1850, it was rapidly taking its place as one of the largest American cities—probably by reason of the barrier of Lake Michigan forcing all travel from the East to the West and Northwest to turn southward to this point. Thus we find that to-day practically every great transcontinental railroad passes through Chicago.

Water-Supply. Chicago is not ideally situated for the development of a metropolis. It did, however, have close at hand the most important facility—an ample water-supply. Chicago has always obtained its water from Lake Michigan, and even to-day there is no other available source of supply. The original intake cribs were located about two miles offshore and were constructed in 1867. With growing pollution of the lake, these intakes have been carried farther out.

Sewerage. The sewerage system of the city was begun in 1856. Most of the sewers emptied into the Chicago River, although others discharged directly onto the lake front. During ordinary weather, the Chicago River was a sluggish stream, with practically no flow into the lake at the lower end, and thus large deposits, of a rather offensive character, were formed. During heavy rains and storms these deposits and the sewage were soon carried to the water intakes. Street and surface washings followed the same course as the sewage, although they were less objectionable. These contaminating influences had their effect upon the water-supply, and brought about unhealthful conditions in the community. The death rate from typhoid fever was as high as 174 per 100,000.

Commission of Investigation. Thus, in 1886, as a result of popular demand, a commission was appointed by the city to investigate the entire problem carefully. This commission was composed of Rudolph Hering, Samuel C. Artingstall and Benezette Williams. The report of this commission was made in 1887, and stated that there were three practical methods of getting rid of the sewage, as follows:

1. Discharge into Lake Michigan.
2. Disposal on land.
3. Discharge into the Des Plaines River and thus into the Illinois and the Mississippi.

Of these three methods, the last was the only one that met with the approval of the commission. At this time the art of sewage disposal had not developed to a degree which provided for treatment by artificial means, or by any method which could be recommended for a city like Chicago. Developments thus far had demonstrated the impracticability of land treatment, such as the method used at Paris and Berlin, and the inadvisability of chemical treatment for the removal of suspended solids, such as English cities were using. No large city in the world was treating its sewage.

The increasing need to preserve its water-supply, remembering that neither then nor now was any other source available, led to the recommendation of the reversal of the Chicago River to flow away from the lake. It was also recommended that sufficient water be withdrawn from the lake to dilute the sewage at the rate of four cubic feet per second per thousand persons.

AUTHORIZATION OF DRAINAGE CANAL

Creation of Sanitary District. In order to arrive at some permanent solution of the problem, the Illinois legislature, in 1889, passed an act creating the Sanitary District of Chicago, for the primary purpose of providing the legislative, administrative and financial machinery to carry on the work and to divert the sewage of Chicago and adjacent towns away from Lake Michigan. The Sanitary District is an independent political subdivision of the State, with the power to construct sewage-treatment and sewage-disposal plants, drainage canals, and all necessary appurtenances. It is allowed taxes up to a maximum rate of two-thirds of one per cent. of the assessed valuation and can issue bonds, for permanent improvements, to the amount of three per cent. of the assessed valuation. The Sanitary District has no control over, or legal connection with, the city of Chicago, and hence has no authority over such usual municipal activities as water-supply, construction of ordinary sewers, care of streets, and so on.

The Sanitary District, in 1924, covered an area of 437 square

miles, with a population of 3,300,000. It includes, besides the whole of Chicago, 49 other cities and villages, with a total assessed valuation of about $2,000,000,000. The population is increasing steadily at the rate of about 70,000 persons a year, and the assessed valuation increases about $50,000,000 a year.

The most important work of the Sanitary District was the construction of the main drainage canal, from the South branch of the Chicago River to the control works at Lockport on the Des Plaines River, a distance of 28 miles. The canal very closely parallels the old Illinois and Michigan Canal and obliterates it for a portion of its length. Its construction was started in 1892 and water was turned in in January, 1900. For 15 miles of the distance the canal was cut out of solid rock, 160 feet wide at the surface and 24 feet deep. It was designed for a capacity of 10,000 cubic feet per second, in order to carry 3 1/3 cubic feet per second per thousand persons, as prescribed in the act creating the district.

The Trustees of the Sanitary District evidently did not believe that the authority of the War Department of the United States was necessary to permit its construction. It was not until 1896, when the work was well under way, that they requested, from the Secretary of War, a permit to widen and deepen the South branch of the Chicago River, in order that it might have a capacity in excess of 5000 cubic feet per second. Further permits respecting the Chicago River improvements were granted. Besides the construction of the main channel, and the straightening and dredging of 20 miles of the Chicago and Des Plaines rivers, the Calumet-Sag channel, 16 miles long, was built from the Little Calumet River to a junction with the main drainage canal at Sag. This was begun in 1911 and completed in 1922, with a capacity of 2000 cubic feet per second. Many other supplementary works were constructed, such as 20 highway and railway bridges, pumping stations, intercepting sewers, and so on. This entire dilution project thus far has cost $100,000,000.

Beneficial Results. This project represents a welfare value which will be appraised more and more highly with the passage of years. The canal accomplished its purpose—it saved the city water-supply, provided a major link in the Lakes-to-the-Gulf Waterway, incidentally supplied power, and led to a remarkable development of bathing beaches on the shores of Lake Michigan. These bathing beaches

accommodate about 3,000,000 people each year, possibly only by keeping the sewage out of the lake.

The success of the work must be measured mostly, however, by the mortality records of the Sanitary District. The highest death rate from typhoid fever of 174 per 100,000, in 1891, has been reduced to the present figure of 1.1 per 100,000. Chicago's rate is the lowest of any large lake city in the country, as shown in Table I, which indicates the respective rates per 100,000.

TABLE I. AVERAGE TYPHOID FEVER DEATH RATES IN CITIES OF THE GREAT LAKES REGION, 1920-1923

Chicago	1.32
Milwaukee	1.88
Detroit	5.02
Cleveland	2.60
Buffalo	4.23
Rochester	2.15
Hamilton, Ont	3.70
Toronto, Ont	2.20
Pittsburgh	2.80

Some of the largest and best hotels, a stadium, an elaborate municipal pier, the Field Museum and a number of parks are now located on the lake front. Without clean lake water many of these could not have been built at the present locations.

The opening of the drainage canal brought about a great improvement in conditions along the Des Plaines and Illinois rivers. Scientific investigations showed such effective purification in these rivers that St. Louis, in 1906, lost its suit in the United States Supreme Court, to stop the discharge of Chicago's sewage down the Illinois River, and thence into the Missisippi.

Injurious Effects. The opening of the drainage canal, and reversing the flow of the Chicago River, were followed by certain injurious effects. The first to be noticed was the flood conditions in the Illinois River. The effect of the diversion on these conditions, however, is slight, and the great increase in flood heights on the Illinois River is due chiefly to the faulty construction of levees. These embankments were constructed mainly for the purpose of reclaiming bottom lands for agricultural purposes, and thus between 200,000

and 300,000 acres of land have been recovered for use. Such construction has been largely since the opening of the main drainage canal, in 1900, and with full knowledge of the state action in directing that a certain flow be added to the river.

The location of these levees was not supervised by either the state or the federal government. For the most part, they were built where individual owners wished, or where the local levee district determined, without regard to the effect in constricting the flood channel of the river. The advisability of building them at all was at least debatable, from the standpoint of public interest, as they shut off the chief breeding ground for fish and injured what for a time was an important industry. The Illinois state Division of Waterways has shown that the maximum discharge of the Illinois River, during the flood of April, 1922, was 109,000 cubic feet per second at Beardstown, and, further, that the flood height at this place was raised 5.5 feet above what it would have been if uninfluenced by levee construction and that but six inches of the total flood height was to be attributed to the discharge from the Chicago drainage canal. Excessive flood heights in recent years have been caused chiefly by this constriction of the flood channel.

With the opening of the canal and the advent of fresh water from Lake Michigan down the Illinois River, local sewage of the immediate territory was diluted more than before and conditions improved, to the extent that this river became, for a time, second in the United States in the fish industry, and the button industry flourished at Peoria due to the harvest of mollusks. With the increasing discharge of sewage into the Illinois River, the sludge is gradually moving down-stream, thus destroying fish and fauna, and at certain places causing disagreeable and offensive conditions. The main reason, however, for this is that the dilution of the sewage has not kept pace with the needs. To dilute the untreated sewage of the present population of the Sanitary District, at the rate of 3 1/3 cubic feet per second per thousand population, would require a diversion of 15,000 cubic feet per second, while an average of about 8000 or 8500 is all that has been diverted. The diversion has somewhat lowered the levels of the Great Lakes and has been responsible for a small part of the present low stage which is affecting navigation and power interests.

Authority for Withdrawing Water. When the drainage canal was authorized there was no control over the withdrawal of water from the Great Lakes. Prior to 1900, diversions of every kind and character were made from the boundary waters with the consent of local authorities only and without governmental sanction. Previous to the appointment of the International Waterways Commission, in 1905, there was no international supervision of the use of the waters of the Great Lakes. In each country such works were built and such water diverted as desired. In addition to the diversion by the Sanitary District the principal other diversions, in cubic feet per second, are:

Welland Canal	4,500
New York State Barge Canal	1,000
Black Rock Ship Canal	700
Canadian power companies	36,000
United States power companies	20,000

However, none of these figures was legally authorized until the boundary waters treaty between the United States and the British government in 1910. The international treaty of 1910 permitted Canada to divert 36,000 cubic feet per second, and the United States 20,000 cubic feet per second, at Niagara Falls for power purposes. There seems to be no definite statement anywhere as to the reason for this difference. Diversion of water from Lake Michigan might have been a consideration, although not legally recognized or mentioned in an international treaty, because the whole lake and its entire drainage area lie within the boundary of the United States. This idea seems to be implied in the following quotation from Secretary Root's statement, in 1906, before the Foreign Relations Committee of the Senate:

"We are now taking 10,000 cubic feet per second out of Lake Michigan at Chicago and I refuse to permit them to say anything in the Treaty about it. I would not permit them to say anything about Lake Michigan. I would not have anything in the Treaty about it and under the circumstances I thought it better not to kick about this 36,000. They consented to leave out of this Treaty any reference to the Drainage Canal and we are now taking 10,000 cubic feet per second for the Drainage Canal which really comes out of this Lake System."

Senator Lodge, in discussing the act authorizing the treaty, said:

"The fact that it must be a matter of treaty while it is a protection also, I think warrants me in saying that what Canada desires is not to limit in any way the outflow of water at Chicago, but to be able to have a corresponding amount credited to her when they come to an agreement as to how much water each country may divert from the stream."

The International Joint Commission, in its report published in 1924, analyzes the boundary waters treaty of 1910 and recognizes Chicago's right under the treaty to divert 10,000 cubic feet per second of water as indicated by the following statement:

"It is understood that in allowing the larger amount for Canada the facts were taken into account that the great bulk of the Horse Shoe Falls lies in Canadian territory and that Chicago was diverting a considerable amount of water from Lake Michigan which would otherwise go over the Niagara Falls."

There can be no doubt that all the parties who represented the two countries, in drawing up the International Waterways Agreement of 1910, were well aware of the diversion of approximately 10,000 cubic feet per second at Chicago, and it is generally conceded that this diversion was taken into consideration in fixing the larger quantity of water allotted to Canada at Niagara Falls. It is true that no mention of this diversion is specifically made in the treaty, and there is good reason that none should have been made. As early as 1827 Great Britain refused to negotiate with America in regard to navigation of the St. Lawrence on that part of the stream where both shores are in Canadian territory. Even now, in stating the problem to be considered by the Joint Engineering Commission, representing Canada and the United States, the former insists upon excluding from the citation any reference to the portion of the St. Lawrence not a boundary water. As previously mentioned, Lake Michigan, with all its shores and all its drainage area, lies solely within the United States.

But even assuming that the international treaty did apply to Lake Michigan, the United States has the right to permit the diversion at Chicago without consulting Canadian authorities, or in any way infringing on the guaranties or upon the spirit of the international treaty. This document entirely safeguards the interests of the Chicago Sanitary District, for Article 8 of this treaty sets forth the precedence in the uses of boundary waters as follows:

1. "Uses for domestic and sanitary purposes."
2. "Uses for navigation including the service of canals for purposes of navigation."
3. "Uses for power and for irrigation purposes."

Not only is the use for domestic and sanitary purposes put in the first class, but further provision is made in Article 5 of the treaty, which explains the diversion for water-power purposes by saying "That these limitations shall not apply to the diversion of water for sanitary or domestic purposes." Moreover, this significant provision is found in the treaty: "The foregoing provision shall not apply to or disturb any *existing* uses of boundary waters on either side of the boundary."

The question has been raised as to the right of the Chicago Sanitary District to reverse the flow of the Chicago River because in so doing it took the water from one drainage area and diverted it to another. Chicago, however, is rightfully considered on the watershed of the Mississippi River. The United States Supreme Court, in 1906, said:

"It is enough to say that Illinois brought Chicago into the Mississippi watershed, pursuant not only of its own statute, but also of the acts of Congress of March 30, 1822, and March 2, 1827, when land grants were made for the construction of such canal."

The first permit to construct the connecting channel, or rather the deepening of the Chicago River, was made by the Secretary of War, in 1896. Subsequent permits to widen and deepen the river channel were given in 1897, 1898, 1899 and 1900. The permit by the Secretary of War to open the drainage canal, in 1899, provided no restrictions as to the amount of water to be used, but the limiting condition was that it should not produce disturbing and unnavigable currents in the Chicago River. Certainly permits to build so costly a work, calling for the use of a definite amount of water, would, in good faith, imply the granting of the additional right to take the water required for such use. This apparently was the idea which prevailed.

As the result of the current becoming rather rapid, and at times harmful to navigation, in the crooked Chicago River, the Secretary of War, in 1901, found it necessary to restrict the flow to 3333 cubic

feet per second. In July of the same year, however, he modified its flow to 5000 cubic feet per second from 4:00 p. m. to midnight; and, in December, again changed the diversion to 4167 cubic feet per second during the whole 24 hours of the day. In January of 1903 another permit, allowing 5833 cubic feet per second during the closed navigation season, was issued. In March of the same year a diversion of 4167 cubic feet per second was allowed for any period. This was the last permit issued until the recent one of March, 1925.

During the period from 1901 to 1903, when these various permits were issued, the Sanitary District was preparing plans for the deepening and widening of the Chicago River, since it was currents in this river which had caused the limiting permits to be issued by the Secretary of War. Condemnation proceedings for land had already been started. Construction work in accordance with federal permits was started in 1903. The plan called for widening the Chicago River to 200 feet with a 26-foot depth. This was done in order to permit sufficient water to flow through the river so as to operate the main drainage canal at its full capacity, without creating obstruction to navigation. Practically the entire river channel was dredged, all center-pier bridges were removed and replaced by modern-type bascule bridges. The work was finally completed in 1912, at a total cost of approximately $12,500,000.

Program for Development. The sewage from the Sanitary District is probably more difficult to treat by artificial methods than that of any other city in the country, due to the organic wastes from the stockyards and from the industrial plants such as the Corn Products plants. These wastes to-day are estimated to be equivalent to a human population of about 2,000,000 people.

Because of this condition and with an appreciation of the looming situation, the Sanitary District began to study scientific sewage disposal in 1908. Since that time it has spent more time and money in the development of artificial disposal of sewage than has any other city in the world. Many years have been occupied with experimental treatment works, located in various parts of the city, in order to determine the best method of treating the particular kind of sewage from each part of the city. The results of these investigations were taken into consideration in the determination of a future construction program for the treatment of its sewage. The different kinds of treat-

ment for different kinds of sewage are shown in the following tabulation:

Project	Method
Des Plaines River treatment	Activated sludge
Calumet treatment	Imhoff tank and trickling filters
North Side treatment	Activated sludge
Industrial waste treatment	Imhoff tank and trickling filters
Stockyard treatment	Activated sludge
West Side treatment	Imhoff tank and trickling filters
Southwest Side treatment	Imhoff tank and trickling filters

The Sanitary District now treats the sewage of a population of 300,000. The North Side activated sludge plant, now under construction, will take care of 800,000 additional. By 1928, the sewage of 1,400,000 people will be treated. This is more than is treated by any other city in the United States.

The future construction program provides for an expenditure by the end of 1944 of a sum of $125,000,000. Of this sum, $95,000,000 will have been spent by the end of 1939 for sewers and sewage-treatment projects which by that time will take care of all the major sewage-treatment plants. Some $12,000,000 will be spent on the construction of bridges, highways, and the settlement of Illinois valley overflow claims, while $18,000,000 is provided for contingent projects, including the Sanitary District's share of the cost of lake-regulating works and bond expense.

It must be remembered that this expenditure is in addition to the $30,000,000 for treatment works which the Sanitary District has already spent, and does not include the $35,000,000 stated as the probable cost of providing for complete treatment at the West Side and Southwest Side plants by 1955. This construction program, by the end of 1939, will take care of and treat the sewage of an equivalent population of 6,782,000, which includes the industrial wastes equivalent to a population of 2,000,000.

This very clearly shows the fallacy in the argument that Chicago is not willing to do her share in the permanent solution of this difficult problem. Chicago has spent $100,000,000 for sewage disposal alone—more than any other city in the United States.

The contemplated expenditures of cities having a population of over 500,000 are shown in Table II.

TABLE II. EXPENDITURE BY CITIES OF THE FIRST CLASS FOR SEWAGE DISPOSAL AND APPURTENANCES

City	Expended to January 1925	Definitely determined future expenditures	Total, including future expenditures
New York	$ 5,559,000	$ 16,372,000	$ 21,931,000
Chicago (Sanitary District)	125,000,000	125,000,000*	250,000,000
Philadelphia	3,500,000	31,100,000	34,600,000†
Detroit district	1,500,000	....	........‡
Cleveland	6,000,000	10,800,000	16,800,000
St. Louis	....	....	....
Boston and Metropolitan district	26,900,000	....	26,900,000
Baltimore	10,000,000	3,500,000	13,500,000
Los Angeles	6,000,000	5,400,000	12,000,000
Pittsburgh	38,000§	....	38,000§
San Francisco	7,000,000	4,000,000	11,000,000
Buffalo	225,000	....	225,000
Milwaukee	20,000,000	3,000,000	23,000,000

*Amount recommended to be expended prior to 1945.
†Pre-war estimate.
‡Roughly estimated at $35,000,000. A sewage disposal commission is now in process of formation.
§Expenditures for investigations.

Statistics show that 88 per cent. of American cities having a population of over 100,000 use the dilution method for sewage disposal, and Pittsburgh is included in this group.

It is difficult to compare the financial ability of Chicago with other cities, because of the method of valuing property for taxation purposes. It is stated that this is rated at half the full value. Probably one-third is nearer the correct amount. By comparing this with the financial data for all cities in the United States above 500,000 people, we find that, while the assessed valuation is extraordinarily low, the tax rate in Chicago is correspondingly higher than in other places. However, when reduced to terms of tax levy per capita it is seen to be more nearly in accord with the average of other places. See Table III.

TABLE III. FINANCIAL STATISTICS FOR 1922 OF CITIES IN THE UNITED STATES WITH POPULATION EXCEEDING 500,000. DATA FROM UNITED STATES CENSUS

1 Name of city	2 Population (estimated 1922)	3 Net debt per capita	4 Assessed valuation per capita	5 Tax rate per $100 valuation	6 Tax levy per capita
New York	5,839,746	$182.72	$1791	$2.61	$46.81
Chicago	2,833,288	46.35	588	7.25	42.76
Philadelphia	1,894,500	103.38	1606	2.39	34.15
Detroit	993,676*	123.37	1966	2.43	47.74
Cleveland	854,565	135.85	1834	2.34	43.13
St. Louis	788,375	17.99	1429	2.22	31.69
Boston	764,549	110.76	2170	2.47	53.62
Baltimore	762,222	104.84	1312	2.42	31.72
Los Angeles	622,343	110.59	1259	3.81	48.79
Pittsburgh	607,902	123.13	1428	3.41	51.41
San Francisco	525,169	135.30	1171	3.47	40.66
Buffalo	523,886	84.01	1288	3.18	40.97
Milwaukee	477,103	66.97	1493	2.84	42.40
Average		103.00	1490	3.14	42.77
Average, excluding Chicago		108.00	1564	2.80	42.77

*Population for 1920.

Continued Need for Diversion. It is unthinkable to turn the sewage back into the lake again; and it is unreasonable to expect the Sanitary District to complete immediately the projects required to take care of all the sewage by artificial treatment. The Engineering Board of Review has recommended a period of 20 years for the Sanitary District to remedy the situation. Judge Carpenter, in his decree on this subject on June 18, 1923, said:

"On the testimony of the government engineers the Court might, in the exercise of a sound discretion delay the effectiveness of this injunction for from 15 to 25 years, to enable the Sanitary District or the State of Illinois to arrange for other means of disposal of the sewage now handled by the Sanitary District."

In 1923, Major Putnam made a similar recommendation when he said:

"If the City of Chicago undertakes to make certain changes with respect to water supply it will be possible to so cheapen the cost of the sewage treatment work so as to permit their completion by 1940 without any material changes in the financial program."

The decision of Judge Carpenter was confirmed by the United States Supreme Court, in January 1925. After a complete review of the facts and decision of the lower court, Justice Holmes, speaking for the court, said:

> "Probably the dangers to which the city of Chicago will be subjected if the decrease is carried out are exaggerated, but in any event we are not at liberty to consider them here as against the edict of a paramount power.
>
> The decree for an injunction as prayed is affirmed, to go into effect in sixty days—without prejudice to any permit that may be issued by the secretary of war according to law."

The most recent permit, which was issued by the Secretary of War on March 3, 1925, allows a continuance of diversion of 8500 cubic feet per second average, with 11,000 cubic feet per second maximum, until 1929, with this provision:

> "That the Sanitary District of Chicago shall carry out a program of sewage treatment by artificial processes which will provide the equivalent of the complete (100 per cent) treatment of the sewage of a human population of at least 1,200,000 before the expiration of the permit."

Since the total equivalent population by 1929 will probably be three times the number stated above, there will be a great need for diluting water for many years in the future. The situation is, furthermore, much complicated by the reversing of the Chicago and Calumet rivers during storms, thus carrying some of the sewage to the water intakes. This is the result of storm water reaching the rivers in large enough quantities to reverse the hydraulic conditions. It will require efficient management during periods of maximum storm run-offs to control the flow through the drainage canal, so as to reduce to a minimum the time when the Chicago River will reverse and discharge into the lake.

It will be impossible to prevent some reversals of flow in the Chicago River, due to a combination of seiches and extreme storms. However, with good management, *and a flow of 10,000 cubic feet per second,* such reversals can be held to low velocities and for short periods of time. If the diversion from Lake Michigan be restricted to 4167 cubic feet per second, the drainage canal will be filled with water having a low velocity and a flat hydraulic gradient. Under such a condition, from eight to twelve hours would be required, after opening wide the gates at the lower end of the canal, before the water surface in the channel, 36 miles long from the lake to the power-house,

could be drawn down sufficiently to establish the rates of flow required to prevent a discharge into the lakes.

It has been suggested that a lock and flood-gate could be constructed at the mouth of the Chicago River to prevent reversals of flow. This is not advisable because it would be an obstruction to navigation and, even at present, basements and streets are very frequently flooded during storms. A flood-gate building up the head on the sewers would merely add to the difficulty of the situation.

Even with complete sewage treatment and complete water purification, the reversal of the Chicago River should be prevented, because a certain amount of surface drainage will always drain into the river and thus cause some pollution in the water-supply. The great need for a continued dilution of the sewage is intensified by the national interest in Chicago's health. Obviously, such a menace as a contaminated water-supply affects not only the people of Chicago, but also its 300,000 floating population. It is estimated that annually there are upwards of 69,000,000 people coming into Chicago, tarrying for varying periods, and going out; so, naturally, any epidemic occurring in Chicago would affect all parts of the United States.

Conditions on the lake front in Chicago are different from those of Cleveland, Buffalo and Detroit, because there are no currents at this particular end of the lake. Sewage entering the lake at this point is merely washed back and forth and thus allowed to decompose and become offensive. At other cities there are sufficient currents to carry these wastes far out into the lake and away from the immediate vicinity of the city.

CAUSE OF THE CONTROVERSY

Water-Levels on Great Lakes. The withdrawal of any water lowers the lake somewhat. The fluctuations in the monthly mean height of each of the Great Lakes year by year and month by month for the past 65 years, as determined by daily observation at several points on each lake, show that all the lakes rise and fall in irregular cycles of several years' duration. In December, 1895, Lake Michigan and Lake Huron were substantially as low as at present, and Lake Erie was as low or lower in 1902, 1895, 1873, and 1867. These fluctuations are chiefly due to climatic causes and it is certain that all of the lakes will rise again.

The low levels of the Great Lakes, during recent years, have averaged about three feet below those of six or eight years ago, and in Lake Michigan and Lake Huron they are four feet lower than 37 years ago. These low levels have caused injury to navigation interests by preventing full loading of the larger boats. It has been estimated that 0.1 of a foot lowering of the lake level will reduce the loading capacity of the average lake boat by 50 tons and cause a loss of about $45 per trip per boat.

The following is a list of causes which will explain the present low stages of Lake Michigan and Lake Huron. The approximate amount of lowering below normal is stated in inches:

"1.	Unusually light rainfall combined with unusually large evaporation during the five years 1919 to 1923	13 inches.
2.	The fall from Lake Huron to Lake Erie along the St. Clair and Detroit Rivers during 1897-1923 inclusive, averaged less than in 1860-1885, inclusive. This explains a lower stage of Lakes Michigan and Huron by	8 inches.
3.	Abstraction of water from Lake Michigan at Chicago	5 inches.
4.	Retention by the existing regulating works of water in Lake Superior which would otherwise have flowed into the lower lakes	3 inches.
5.	Diversions of water from Lake Erie and from the Niagara River by the Welland Canal, the New York State Barge Canal, the Black Rock Navigation Canal and the power canals at Niagara Falls, which have lowered Lake Erie about 4.4 inches and thus by backwater effect through the Detroit and St. Clair Rivers have lowered Lakes Huron and Michigan	2 inches.
	Total lowering of Lakes Michigan and Huron below normal	31 inches."

It will thus be seen that the effect of withdrawal at Chicago is much less than commonly supposed, as it causes only about one-sitxh of the entire lowering about which some people are complaining.

From the above statement it will be noted that the withdrawal of water from Lake Michigan at Chicago lowers the lakes about five inches. However, this is based upon the present diversion. The permit from the Secretary of War in 1903 allowed a diversion of 4167 cubic feet per second, so that the effect of the withdrawal in excess of the amount permitted is not over three inches.

Uses of Water of Lake System. There is, however, an important use for navigation purposes of the water diverted at Chicago. For more than 100 years both the United States and the state of Illinois have proceeded on a policy of improving the navigation facilities of the country by connecting the Great Lakes through Chicago with the Gulf of Mexico. The main drainage canal of the Sanitary District is so designed as to be available for navigation. It provides the most expensive part of the section of the Lakes-to-the-Gulf Waterway. The state of Illinois is now spending $20,000,000 in constructing the next section and, when completed, this will form a nine-foot barge waterway, with five locks 110 feet wide by 600 feet long, from Lake Michigan to the Illinois River at Utica, about 100 miles from Chicago. It has been found that the saving in cost of construction and operation of this waterway, with a diversion of 10,000 cubic feet per second, as compared to that with a diversion of 4167 cubic feet per second, is over $5,000,000.

The improved Illinois waterway, with a nine-foot barge canal, will be an adequate connection from the Great Lakes to the Gulf and an advantage to the entire Mississippi valley. If there is sufficient diversion so as to permit the completion of this waterway at moderate cost, it should be of almost immediate benefit to the Middle West, because in all probability, it will be completed within the next three or four years.

At present there is no appreciable loss of economic power in the Niagara or St. Lawrence rivers through the withdrawal of Lake Michigan water at Chicago or until 95 per cent. of power is developed. The gross power available on the St. Lawrence River is about 5,000,000 electric horse-power. This can not all be developed. The net power available depends upon the method of development and has been variously estimated at 3,000,000 to 4,000,000 electric horse-power. At present 300,000 electric horse-power in round numbers is developed on the St. Lawrence River.

Under existing treaty restrictions, for the use of water for power at Niagara Falls, the waters diverted from Lake Michigan into the main drainage canal could not be utilized for power production at Niagara Falls, even if diversion at Chicago were discontinued. If there were no restrictions on the use of water for power at Niagara, the use in the Illinois River of 10,000 cubic feet per second, or 1/20 of the flow of the Niagara River, would cause no reduction of avail-

able power until the other 19/20 had been developed. At present ¼ of the total flow is used for power on the Niagara River.

The market demand for power, as well as its value, is very great in the Illinois valley. At Niagara Falls it is comparatively much less because it is used in large blocks for chemical and industrial purposes. The Chicago diversion causes no economic power loss. While the maximum net available head on the Niagara River is 305 feet and that on the Chicago-Des Plaines-Illinois River only 122 feet, the actual monetary value of a cubic foot of water per second for power purposes in Illinois is greater than that at Niagara.

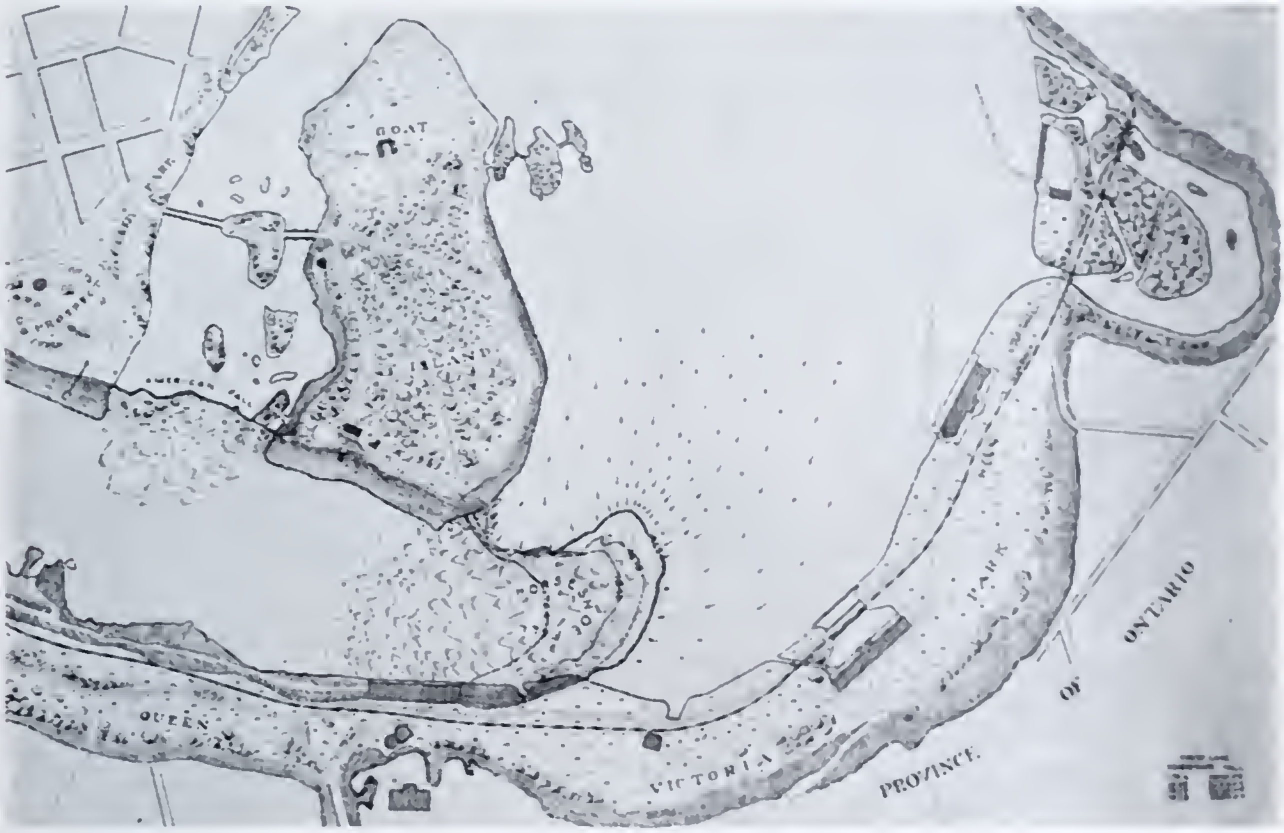

Fig. 3. Recession of Horseshoe Falls, 1764-1923.

An item of vast importance is the preservation of Niagara Falls, which is certainly suffering deterioration by reason of the erosion of the bed rock, principally at the apex of the Canadian or Horseshoe Falls. This is shown in Fig. 3. The present rate of recession has been determined as averaging four to six feet a year, and is constantly taking such shape that the injury becomes progressively more serious. The whole nation is interested in the preservation of such an international asset. The Chicago diversion produces no appreciable effect on the beauty of Niagara, because it is not the quantity but the distribution of the flow which affects this.

This condition has been demonstrated by a large working model

constructed by the power company at Niagara Falls. Fig. 4 shows this model operating practically under present conditions with 56,000 feet per second diverted according to present treaty provisions out of approximately 200,000 cubic feet per second flow in the Niagara River. Fig. 5 shows the same model, but with approximately half of the total flow of the river diverted for power purposes and with no remedial works constructed. Fig. 6 is another view of the model diverting about half of the water for power purposes, but with a weir constructed above the crest of the Horseshoe Falls to distribute

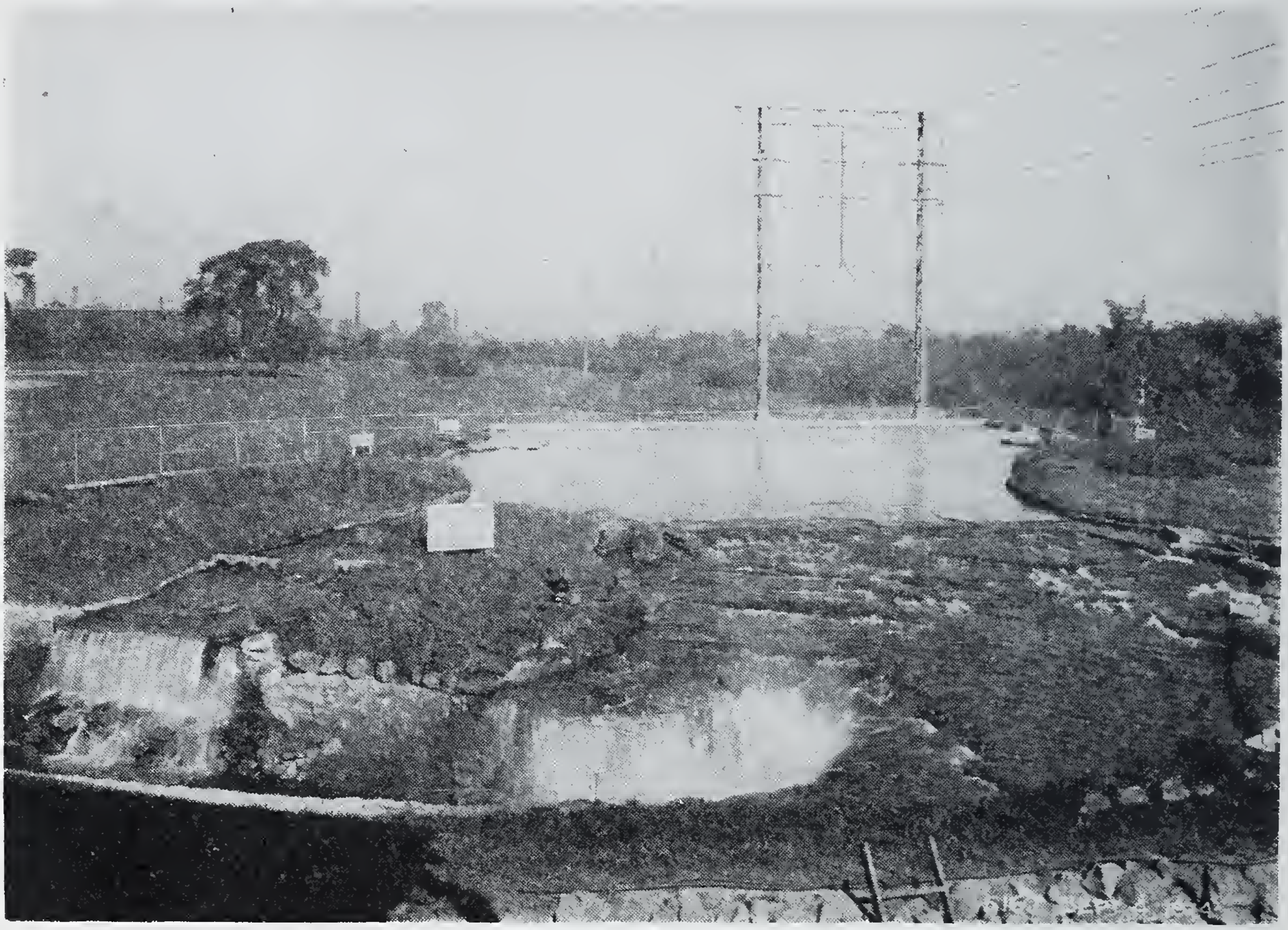

Fig. 4. Model of Niagara Falls. Present Condition.

the water over the entire crest. Fig. 7 shows the same conditions as Fig. 6, but with an additional weir constructed to raise the level in the upper pool so as to maintain the natural flow over the American Falls. The beneficial effect upon the American Falls from this point of view is clearly evident by comparing Fig. 6 and Fig. 7.

Practical Remedy by Lake Regulating. Regulating and control works are a sounder and saner solution of the entire complicated problem. Such is better than can possibly be effected in any other way, even if Chicago diversion were eliminated. The practicability of regulating and control works has been demonstrated by works similar in

Fig. 5. Model of Niagara Falls. Half of Present Flow Diverted.

Fig 6. Model of Niagara Falls. Half of Present Flow Diverted. Distribution of Water Controlled by Weir.

character previously constructed and now in operation. The regulating and control works on the St. Mary's River, completed in 1916, which control the level and outflow from Lake Superior, afford an illustration of the feasibility of construction and practicability of operation of a regulating works on a Great Lakes outlet.

The water yield of Lake Superior has been about 25 per cent. below normal during the past few years owing to deficient rainfall. The regulating works have maintained the level of Lake Superior at a nearly uniform high stage (equal to that of 10 years ago) down to

Fig. 7. Model of Niagara Falls. Half of Present Flow Diverted. Distribution of Water Controlled by Two Weirs, and Natural Flow Maintained over American Falls.

the present date and have supplied water for power in a manner better adapted for each power requirement than if no regulating works had been constructed. The present level of Lake Superior is from 12 to 18 inches higher than it would have been without regulating works.

Structures similar to those proposed for the Niagara River have been in successful operation for more than ten years on the New York State Barge Canal. It is practicable, by means of regulating works at the outlets of Lake Erie and Lake Huron, together with the

existing works at the outlet of Lake Superior, to maintain, under all ordinary conditions, a minimum flow in the Niagara River of from 180,000 to 200,000 cubic feet per second. Such will provide at the same time lake depths for navigation, averaging two feet greater than those under the unregulated natural conditions.

Such regulation has been previously recommended by the American Deep Waterways Commission, in 1900; by the International Joint Commission, in 1913, and, later, by Col. J. G. Warren, in 1920. Chicago has always fostered this idea and has agreed to pay its share of the construction cost.

In view of the changed conditions and the broader present outlook for joint control of the levels and the discharges of all the Great Lakes, the Engineering Board of Review, through Committee No. 2, has given attention to a new proposition for controlling the outflow from Lake Erie and regulating its level. This will be in the form of drop-gate weirs built under the piers of a bridge, located about one mile up-stream from Niagara Falls. The control works will consist of a series of 60 large weirs, each with a clear span of 74 feet. They will be designed to increase the height in the Chippewa pool to any desired amount up to 10 feet. The whole will extend entirely across the river, which here is nearly one mile in width. Besides these weirs, three artificial islands will be placed down-stream, so that either the American or the Canadian channel can be unwatered quickly and inexpensively, at any time of moderate discharge, for repairs on the crest of the falls. This will be accomplished by closing the gates at the islands, and by closing the gates under one-half of the main bridge, while gates under the other half are wide open. While having the Canadian channel unwatered, it is proposed to build a protective weir around the Horseshoe Falls, so as to distribute the water more evenly over the whole falls and thus very greatly increase the scenic beauty.

It is proposed also to build works somewhat similar to this in the St. Clair and Detroit rivers, but not including gates (and thus locks) in the ship channel. There can be no question as to the great value of these regulating and control works to both Canada and the United States; first, in the preservation of Niagara Falls; second, in the increase in water power; and, third, in the increase in navigation depth.

SUMMARY AND CONCLUSION

No community can live unto itself; likewise no one can have his own way for a long time. Adjustments must be made on the basis of the greatest good to the greatest number. The principles of conservation must ultimately triumph.

Chicago to-day is in the same position as the railroads were a generation ago; not a friend, but many enemies. The opposing claims of the two nations, and of the various states and municipalities, furnish greater obstacles to full development than do the engineering difficulties, and yet these opposing claims are more largely sentimental than real. They can and will be adjusted through a better understanding of all the conditions. There is no doubt but that there must and will be a better understanding when the public in general is fully informed and is convinced that under the largest and best development of these natural resources both nations will gain as well as the various political divisions.

In summing up the equities and conveniences, it may be said that the best and wisest conservation and use of the waters of the Great Lakes system will enable added comfort and prosperity to come to the major portion of the people of two rapidly growing nations. No more can be gained to anyone by destroying Chicago than was accomplished by nearly bankrupting railroads by harsh regulatory methods; or what the nations of the world will gain now by keeping a foot upon Germany's neck and not permitting her to rise in prosperity and influence. Pittsburgh as well as the whole country is interested in a sane and fair solution. We can fight and gain three inches for Pittsburgh's ore and coal carriers, or we can work together and get three feet more for navigation and power—worth billions to the country as well as to ourselves.

DISCUSSION

Mr. W. B. Spellmire, *Chairman*:* This paper is of much interest, as it is not only related to the situation in the Chicago Sanitary District, but to some extent involves the power developments at Niagara Falls on both the American and Canadian sides. The paper is also of special interest in view of the inspection trip of the Society, planned for Buffalo and Niagara Falls.

The paper is now open for discussion.

Mr. F. F. Espenschied:† It has been a great privilege for us to hear a talk of this character on a subject which has occupied so much attention all over the United States and Canada. Some of us have spent some time on the Great Lakes, and north and south and west of them. It was my pleasure to be on Lake Superior last summer. They showed me how the beach had receded at Fort William. I do not know how many feet it was, but they attributed it to the Chicago drainage canal. Lake Superior is not at all affected by what goes out of Lake Michigan, because Lake Superior is considerably higher than Lake Michigan. The tendency on the Great Lakes, it seems, is to blame everything on Chicago, even things with which Chicago has nothing at all to do. It is evident that the timber has been cut off and burned off at a terrific rate, and this has had a marked effect upon the level of all the lakes. The level of Lake Superior, even with the remedial works at the "Soo," has been greatly affected during recent years and you can see where the former shore line was. It strikes me as ridiculous to hear people on the St. Lawrence blame Chicago for many things which seem to be entirely beyond the influence of Chicago.

The measurements Mr. Knowles has shown of lake levels are instructive, but I do not think he has made clear enough the fact that, aside from rainfall, the effect of deforesting that northern country, including the state of Michigan, has had a marked effect on the minimum flow in the St. Lawrence valley. I feel highly rewarded for coming here this evening to hear a very important subject so broadly and ably treated. For this a most hearty vote of thanks is due Mr. Knowles.

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†Engineering Sales, Pittsburgh.

Mr. George S. Davison:* I call attention to the table that Mr. Knowles has exhibited which shows the tax levies per capita in a number of large cities. Pittsburgh is near the top with $51.21; Chicago is $42.76. Mr. Knowles has given many astounding figures with regard to what Chicago has and is expending on its sewage system, and yet the per capita tax there is not as high as in Pittsburgh. Pittsburgh has had no sewage problems, and yet there must be some explanation of why its per capita tax levy is so high in comparison with other cities. I think it is due entirely to the rugged topography within the city. First, this topography makes it impossible to house as many people per unit of area as in a flat city like Chicago, New York, and other cities that might be mentioned. Furthermore, the problems in public improvements here, such as the building and maintenance of highways, including bridges and also water service, require expenditures not necessary in other cities.

There is another important difference in the financial situation of such cities as Chicago and New York, as compared with Pittsburgh, with reference to the need of public improvements and the financial program necessary to carry them out. The two former cities are the gateways through which goods and peoples pass, but tarry awhile, this tarrying causing a large tribute to find its way through many channels into the public treasury. Pittsburgh does not enjoy the advantages of being a gateway. Its taxes for public improvements finally settle down on its own people.

Mr. J. P. Leaf:† This is a great source of pleasure to me and this particular subject is one that I have been intimately acquainted with ever since it started. I happened to be well acquainted with one of the commissioners that built the canal and he took me over it and showed me what had been accomplished. I remember the regulatory works at Lockport. He said he was absolutely opposed to it—that we ought not to have regulatory works, and that some court injunction could stop the flow of water; and they have had an argument over that ever since.

I was also very much interested in the geology. In recent times the water discharged through the Des Plaines valley. The fact is that, even before this drainage canal was built, the floods put part of the

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†Beaver County Commissioner and Consulting Engineer, Rochester, Pa.

water of the Chicago River over into the Des Plaines valley and the natural outflow of the Chicago River was both into the lake and into the river. I was surprised that Mr. Knowles said the ridge was only eight feet; I should have thought it was 30 feet, at least. I know there is a 40-foot cut in the canal. I am also concerned for fear the wind will blow the sands over into the lake and open it up in that way.

I have heard the discussion in the United States Rivers and Harbors Commission and I have heard the Canadian side as well as our own side, and I am convinced that Chicago has a perfect right to take the 10,000 feet per second she takes, and even more. The diversion of the water she is taking is not doing anybody else any harm and it is doing Chicago a lot of good, and not only Chicago, but also St. Louis and the entire central valley, by furnishing water for navigation and sewage dilution. St. Louis was very much put out because the drainage of sewage was past her front, but she did not say anything about turning her own sewage into the river below. The main kick about this comes from the fact that people in other parts of the country want to use the water and they are afraid Chicago will take away some of that water. Even Canada is making some diversion of the water at Niagara Falls. We were asleep when we allowed them to take more water than the United States. But there is plenty there yet. The Chicago drainage canal takes about five per cent. of the water that goes over the falls when it takes 10,000 feet per second. It can not possibly affect the power at Niagara Falls until about 90 per cent. of the available power is used, and probably not over 20 per cent. of the power at the falls is used.

I was very much interested in the controlling works to be placed at the end of Lake Erie. That will correct this 20 per cent., to use the greatest amount attributed to the Chicago drainage canal by Canada. I believe that Chicago people admit 10 per cent. due to the diversion. The 30 inches that is bothering navigation on Lake Erie can be corrected, along with the five inches the Chicago drainage canal takes, and it would be a great thing for Lake Erie, and I believe that Chicago should contribute to the cost of the controlling works. The international bridge is a worth-while proposition and economically all right.

I think, as an Engineers' Society, we should say that Chicago needs the water and it would be a great advantage to the entire coun-

try. I agree with the gentleman who spoke first that we are under a great obligation to Mr. Knowles for giving such an intelligent discussion, and he has covered the ground very impartially. I almost thought part of the time that he was representing Canada.

MR. W. B. SPELLMIRE, *Chairman*: What would ultimately lead to the condition where water would cease to flow out the St. Lawrence River?

MR. MORRIS KNOWLES: The geologist who wrote the book from which these charts were taken tells us that the changes began some 25,000 or 30,000 years ago and are going on progressively at this time. Furthermore, changes are now in progress continually, and probably will continue, which means a tilting of the earth's surface like a hinge, which will so raise the eastern border of the lakes that the water will begin to come down the Des Plaines valley again. Perhaps it will begin to happen about 500 to 600 years from now and be completed about 3500 years from now.

MR. B. A. LUDGATE:* As it will require a tilting or general surface rise of about eight feet to stop the flow of water in Niagara River, is it not also probable that the river bed is being rapidly lowered by the general erosion, so that the river will never disappear? Does the international boundary line change its position automatically with the change of the river channel?

MR. MORRIS KNOWLES: The international boundaries have been fixed by survey commissions from time to time. The question of interest is, if the river changes its course and the river is the boundary, does the territorial area change? You will have to ask the lawyers about that.

MR. A. E. BLAKE:† Would it be possible to scout around the Arctic watershed and divert any of its water to the Great Lakes?

MR. MORRIS KNOWLES: In connection with canalization schemes, Canada is interested in waterways from the Great Lakes

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†Pittsburgh Representative, U. G. I. Contracting Co.

not only through the St. Lawrence, but also out through Hudson Bay, and another that will get to the St. Lawrence through the Georgian Bay and the Ottawa River without going through Lake Erie. Canada has made studies of these routes from time to time. Certain rivers north of Lake Superior and south of Hudson Bay could be impounded and run water into Lake Superior and not into Hudson Bay, thus furnishing a navigable connection across the headwaters. This may be rather a dream and a long way off.

MR. S. C. MCKEE:* Has the fall of 31 inches been uniform in Lake Michigan, Lake Huron, and Lake Erie?

MR. MORRIS KNOWLES: Lake Huron and Lake Michigan are always about the same. Erie is sometimes a little different, but 35 inches is the average that it is lower than it has been for an average of 60 years.

MR. F. F. ESPENSCHIED: What is the estimated cost of that remedial work on the Niagara River? To me it would appear not only well worth its cost, but practically an international necessity right now.

MR. MORRIS KNOWLES: About $12,000,000.

MR. WINTERS HAYDOCK:† The speaker has referred only briefly to that very interesting question of the Lakes-to-the-Sea ship canal. I would like to ask what effect that canal would have on the level of the lakes, in case it were to be used to such an extent as to make its construction economically advisable? If the great amount of money to be put into that canal is to be wisely spent, it means that a great deal of shipping must lock through it and a great deal of water must be taken by the locks.

A second question which I wish to ask is, in what way does the raising of the level of Lake Superior three inches effect a three-inch drop in the level of the rest of the lake system The total amount of water to be discharged from Lake Superior would be the same irrespective of what its level might be.

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†Chief Engineer, Bureau of Traffic Relief, City of Pittsburgh, Pittsburgh.

My last question is this. Suppose the proposed controlling system is built above the crest of the falls. A method will then be provided by which one of the falls may be dewatered at will. We know that the crest of the falls is receding about five feet in horizontal distance every year. The proposed method of control would cut down that process of attrition very materially. It might cut it down to a very small amount so that there would be almost no recession. If the recession were not ended entirely would it be possible to armor the crest and make the falls absolutely permanent in their present form and shape?

Mr. Morris Knowles: The construction of a ship canal from the Great Lakes system through the St. Lawrence to the Atlantic would affect in no wise any system of regulation of the lakes except to make it even more apparent that it is wise to have such. So far as anyone has pictured it at the present time (though other schemes are possible), the travel from Lake Erie to Lake Ontario would be through the Welland Canal, and that is the way they go now. The effect would be to take more water out of Lake Erie for lockage, and that would accentuate the need of building the regulatory works to hold back water in Lake Erie. So that, if the St. Lawrence navigation scheme goes through, it does not change the principle of regulation, while it would make very definite the advisability of doing it promptly.

That brings us to the second question, the influence which any works built at the outlet of Lake Superior would have in changing the level of Lake Huron or Lake Michigan. We feel sure that the building of regulatory works at the outlet of Lake Erie would hold back water to send down to the Welland Canal for lockage. Lake Superior has had some of the same meteorological and climatological conditions as the other Great Lakes; nevertheless, it has not lowered to the same extent, and the reason is that during the past eight years the water has been held back in Lake Superior and that lake has kept it up. Inasmuch as it has been kept back, Lake Huron and Lake Michigan have been lowered likewise to the extent that they have not received the water from Lake Superior which they would have had if there had been no regulatory works there. In time it will all come out of Lake Superior because Lake Superior will fill. It will not come out as fast in times of rain and flood, but faster when it is

let out in times of low water, and that is the same scheme of regulation as is proposed to prevent floods at Pittsburgh.

With regard to the protection of Niagara Falls, I think in the last analysis that matter is going to be so apparent to the lovers of scenic beauty that they will cause it to be done when nothing else will. Dewatering will permit getting to the falls in the dry and to determine what is going on. We know that at the apex it is cutting back faster than on the sides. If anything could be done to distribute the water from the apex and to the sides, it would improve the situation and prevent the wearing away of the apex. But whether what you suggest can be accomplished—that is to build a concrete dam at the apex and armor it so it will not cut back—is only conjecture. We do not know what can be done until we get at the falls in the dry and see what is there.

Mr. W. B. Spellmire, *Chairman*: The duplication of the strata on each side of the gorge from Queenstown to Niagara indicates that the action of the water has developed this gorge in what was originaly a flat table land. I believe the bed of the river above the falls consists essentially of a hard, limestone rock and that beneath this is a soft shale, and that the water spilling over the falls undercuts the softer rock until the limestone bed projects unsupported and then breaks off so that the armoring of the crest with the present rate of flow would probably not help.

Mr. Morris Knowles: In further answer to the question of Mr. Ludgate, the rock sill south of Lake Michigan, over which the waters of Lake Chicago once flowed into the Mississippi drainage area, is to-day but eight feet above the common mean level of Lake Michigan and Lake Huron. Therefore, with a rise of some eight feet in the plane from Illinois to the Niagara River, hydraulic conditions would be such as to produce a constant flow from the Great Lakes to the sea, both through the St. Lawrence and the Mississippi. It is not until the tilting has been carried considerably further that the flow of water through the St. Lawrence would be entirely cut off. There is also the possibility of counter actions taking place—new earth movements, and also the affect of attrition of the Niagara River, which may affect the ultimate end.

Mr. Espenschied well calls attention to the possible effect upon meteorological conditions due to the removal of the forests and timber on the watershed of the Great Lakes. This effect, of course, is only problematical, and in an area having such a large body of impounded water there is no practical method yet devised of estimating its effect.

The author is much pleased with the interest which the members have shown in this subject, all of which calls attention to the fact that in problems of such broad national importance, the engineers are leading and taking a prominent part in the solution of these questions. Even though Pittsburgh is not on the Great Lakes, its interest in this subject is so great that it should follow the development closely; not in order that Pittsburgh shipping interests might gain a few inches in lake levels by a narrow policy in regard to the Chicago withdrawal, but in order that sane regulation of the Great Lakes should be carried out. Thus there may be restored to shipping interests over 30 inches of loading capacity, doubling the possibility for power diversion at Niagara Falls and preserving for nature lovers the beauty of the great cataract. Those who made the trip to Buffalo with this Society and saw the model of Niagara Falls in actual operation have a vivid conception of what can be accomplished along this line.

MECHANICAL COAL LOADING*

By N. A. Newdick†

Because of the growing interest in the mechanical loading of coal underground, the next few years will undoubtedly show some splendid progress. We are reliably informed that at this time there are in use 21 different machines for this purpose. If it is assumed that many of these are in an early stage of development, the condition is encouraging. Even though many are never developed into usable machines, the work done with them may be valuable in what it contributes to our rather limited knowledge of this great industrial problem.

The knowledge of the problem of mechanical loading is likely to remain rather limited for some time to come. We believe this to be true, because it is not conceivable that there can be developed any one method, machine or device which can be applied universally and reach a full measure of success. Because of this, each installation will be to some extent an individual problem. Only when a sufficient number of successful installations of different loading devices is made, their performances compared, and the conditions under which they are operating considered, will we begin to acquire a specific knowledge of the subject.

Anything that can be done to hasten the acquirement of this information, its compilation, comparison and publication, will be of great value to the coal-mining industry. The collection of such information is worth an organized effort. It will go a long way towards removing the application of mechanical loading out of the cut-and-try procedure, and placing it where it belongs, in the sphere of real engineering.

Fortunately, much of the information necessary to reach a conclusion regarding the installation of loading equipment may be obtained without the use of a loading machine of any kind. Surprising as it may seem, a good loading machine creates about as many problems as it solves. At least this is true in the limited experience of our company, and under the conditions in which our machines have been developed. It has also been found that the proper solution of these problems is of great value in many unexpected ways, in addition to insuring the success of mechanical loading.

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†The Coloder Co., Inc., Columbus, Ohio.

Most of these problems are those over which a loading machine itself has no control, but which, if not properly solved, may lower the utility of the machine to an extent that may cause its abandonment. Almost all of these vital problems can be solved without using loading machines.

Probably the first among these is the proper preparation of coal for loading. When it is considered that this problem of preparation covers the many methods of cutting, the location, size and depth of shot holes, the nature and quantity of explosive, how the explosive shall be confined, and in what order the charges shall be fired, it becomes obvious that preparation covers considerable territory. Add to this, consideration of the structure of the coal, consideration of the top so far as that may lessen slate hazard; never losing sight of the necessity of producing the maximum percentage of lump. It is also obvious, we believe, that the preparation problem is a local one, and that its solution sometimes varies with different locations in the same mine. It is one of the problems which the loading machine creates but does not solve. Its solution, though, can be closely approached without the use of a loading machine. Before any intending purchaser of a loading machine actually purchases one, he should conduct coal-preparation experiments to a sufficient extent to determine that proper preparation can be effected, just how to do it, and that it can be done in all the sections of his property where loaders will be used. The coal so prepared may be loaded by hand. As these preparation experiments proceed, consideration should be given to floor and roof conditions, also to timbering necessary to suit conditions that exist.

The handling and disposal of slate is another problem the loading machine sometimes creates but does not solve, depending upon conditions. When the room-and-pillar system is used, there are strong advocates of removing all slate, gobbing as much as possible on one side and leaving the pillar-drawing side free, and of gobbing about an equal amount on each side of the room. A discussion of this subject is of little or no value. No matter which method is used, the fact remains that sufficient room must be provided for a loader to operate.

The method of transportation of coal from a loading machine to the mine-cars may have quite a bearing on the disposal of slate, as will be shown later. In any event, a careful consideration of the

transportation problem may be made before the installation of a loading machine. Unlike some of the other problems, a final solution is not necessary if a mine car of 2½ tons capacity or larger is available. What is believed to be the largest tonnage ever loaded in one shift by an underground loading machine was loaded one car at a time. Speculation on the possibilities of conveyors for loading mine-cars from movable loading machines is interesting and stimulating. It seems probable, however, that these conveyors will be auxiliary equipment that may be installed whenever perfected. This problem of the transportation of coal from the loading machine to the mine-cars has been discussed often and fully, and, so far as we know, without arriving at a universal solution.

The practice of loading one car at a time is anything but an ideal condition. Time studies of loading machines operating under average conditions and using this method of loading have shown that the loading machine was actually loading only about 50 per cent. of the total elapsed time. Under favorable car-shifting conditions this percentage is considerably greater, but favorable conditions are not always possible.

It is apparent that the use of a mine-car of the largest capacity possible is a step in the right direction. In installations where mines have been placed entirely on a mechanical-loading basis, the capacity of the cars has been increased by raising the sides and ends. The latter plan makes the best possible use of the equipment already in use, which is nearly always the first step toward success.

A plan has been worked out whereby, in room work in a fairly level seam, continuous room loading can be done. This is accomplished by a double track temporarily laid behind the loading machine. When loading is to begin, an empty car is placed on each track. The car-loading elevator of the loader is swung to discharge over one of the cars. When that car is loaded, the elevator is swung over the other car without stopping the loader. A gathering locomotive pulls the loaded car and replaces it with an empty, the loading conveyor being swung to position over it when the second car of the first two is loaded. This cycle is repeated until loading in that place is completed. A three-throw switch communicating with the room track makes possible the placing of cars as desired. This track arrangement permits the making of rapid car shifts while loading in break

throughs, but gives continuous loading in the rooms only. This plan requires a room 16 to 18 feet wide with a good top, with the slate removed from the room for a considerable distance back from the face.

A close approach to continuous room loading is made by the use of a side track in the room, both ends of which communicate with the room track through ordinary switches. Very rapid car changing may be obtained with this arrangement using two gathering locomotives. The slate must be removed on one side of the room, which should be about 16 to 18 feet wide and have a good top.

Transportation from the loading machine to mine-cars by means of various types of conveyors has been under consideration for years. In 1918, when the first high-capacity loading machine was placed in service, the desirablity of such a method of transportation was evident. Since that time our company has studied this problem at great length, and many plans for accomplishing it have been considered. Considered from a mechanical engineering point of view only, the solution has been found comparatively easy. Any one of several types of conveyors could be used, with almost certain success of rapid loading.

It has not been found so easy to solve the problem and maintain the flexibility of operation so necessary when using mechanical loading. Any auxiliary equipment that interferes with the operation, or with the rapid shifting of a loading machine from one working section to another, is very likely to cost more than it saves. As far as possible, loading equipment should be adaptable to meet the sudden changes sometimes arising in mine operation. Neither has it been found to be an easy task to reconcile this lack of flexibility with the investment in conveyor equipment when the tonnage output is considered.

A volume could be written in an attempt to discuss even partially the number of conveyor methods that have been considered for moving coal from the loader to mine-cars.

The method of using conveyors loaded manually has attracted much attention. Undoubtedly there is a wide field for this method where certain conditions prevail.

When considering the seeming inefficiency of single-car loading, we should not overlook the great advantage of flexible operation. The loaders may work double or triple shifts. For instance, if a sufficient number of working places are prepared, and mine-cars are available, one high-capacity loading machine will load from 900 to

1200 tons every 24 hours, with no other equipment than its attendant car-shifting locomotives. To avoid loss of time in moving from one group of working places to another, the groups should be located as near together as possible, although, since a loader may be transported at a speed of six to eight miles an hour, a mile or even two miles separating the working groups is not a vital matter.

While only the high spots of coal preparation, loading and transportation have been touched upon in the briefest manner possible, we submit that all a loading machine should be asked to do is to load coal. Its output should be dependent on the smallest possible amount of auxiliary equipment.

The proper solving of the various problems incident to mechanical loading has, as previously stated, done much to standardize various mining methods. It has proved to be highly economical to find the best way to do a job, and always to do it that way as long as the surrounding conditions remain fairly constant. Confirmatory evidence of this is seen when operating and cost reports from a group of loading machines are compared, one period with another. These machines have been properly installed and are fairly well operated. Many of them (there are 22 in all) are operating under very unfavorable conditions, but that is part of their job.

A comparison of the cost per ton loaded during the different periods mentioned shows an astonishing uniformity. In this cost is included all labor required for removing the coal from its natural location in the seam to the cars loaded and arranged in trips for the main haulage motor. The local or section supervision labor is also included; also the cost of all explosives, repair parts, labor to install repair parts, oil and supplies of every kind, and also the cost of sprinkling.

Using 10 cents as a base price per ton, the average cost variation for the time periods indicated is as follows:

Period	Percentage
1924	100
January, 1925	98.8
February, 1925	98.5
March, 1925	99.3
Average, January-March, 1925	99.4

In the same periods the average tonnage loaded by each machine per shift was as follows:

274	265	280	260

While the average tonnage loaded per shift is below normal capacity, it is surprising that it is so uniform and so near normal, considering mining conditions and intermittent operating conditions.

By the use of printed report forms, the exact labor cost per ton is calculated at the close of each day's work. Comparison of this cost with the cost of any previous day, or with the average cost of any period, is quickly made; for, whatever value the knowledge of cost may have in mine operation, properly installed mechanical loading by almost any method will help to obtain it. Detailed analysis of the total cost per ton is easily made and yields some very interesting information.

Though, as has been said, mechanical loading creates many problems, experience has shown that the results from proper solutions are worth the effort.

DISCUSSION

Mr. N. G. Alford, *Chairman*:* What is the weight of the machines?

Mr. N. A. Newdick: About the same for both of them: 14 tons for the 29-foot, 8-inch one. The length would depend on the length of the mine-car. The rear end would vary with the mine-car; the front end would be the same.

Mr. N. G. Alford: What size is the mine-car?

Mr. N. A. Newdick: A little over three tons.

Mr. C. E. Lesher:† Why does it require five men?

Mr. N. A. Newdick: It requires the operator, three men ahead, and the car trimmer. Under certain conditions where the preparation is good they need only two men, but so often the preparation is faulty that the third man is needed. He pulls down the hanging coal.

Mr. N. G. Alford: What is the capacity of the new mine-cars that the Pocahontas Fuel Company proposes to use with this machine?

Mr. N. A. Newdick: Five to seven tons, depending on the height of the coal. They will increase the size when the height of the machine permits it. The car stands 21 inches above the rail.

Mr. C. E. Lesher: Is there any particular method of mining?

Mr. N. A. Newdick: Until we began to work on a modified form of long-wall they had worked only the room-and-pillar system, developing rooms and taking the pillars.

Mr. A. P. Cameron:‡ What is the loss of lump size due to loading with the machine?

*Mining Engineer, Howard N. Eavenson & Associates, Pittsburgh.
†Assistant to President, Pittsburgh Coal Co., Pittsburgh.
‡General Manager, Westmoreland Coal Co., Irwin, Pa.

Mr. N. A. Newdick: I have never attempted to measure that. We never thought there was much.

Mr. W. L. Affelder:* I want to substantiate one statement of the speaker, and then ask a question. Someone asked if the roof conditions were always as good as shown in the pictures. I have a report on this particular installation made by Mr. Johnson, of the United States Bureau of Mines, and he states that it is a practice of the officials to select places for machine work which they consider too bad for hand loading. In other words, they are not saving the machine; they are putting it at a disadvantage, if anything, by selecting places which are extremely difficult and in some cases too difficult for hand loading.

The speaker, in the early part of his paper, mentioned something about the cost of coal delivered at the main partings. He mentioned the fact that the cost included the shooting of the coal, the cost of explosives, the cost of repair parts, and installation and haulage; but he failed, as far as I noticed, to mention any definite figure of cost. Did he purposely avoid going into costs, or is he willing to let us know what it does cost?

Mr. N. A. Newdick: I do not know whether Mr. Affelder is serious in his question or not. What I intended to convey by that comparison was to establish the statement as to the uniformity of cost. That uniformity was expressed in the percentages I named, and I meant, by mentioning all the different parts of the cycle of mining that went into this cost, that the entire cost was in that percentage—not just the loading cost. That was the cost of mining from removing the coal from its natural position in the seam to the mine-cars, and in trips ready for the mine-haulage motor. It does not reflect merely the cost of loading; it is uniformity in the cost of mining.

Mr. W. L. Affelder: That is the difficulty in the Pittsburgh district. There has been too much uniformity in high cost. We would like to break that uniformity. Can you tell us the average number of men on a complete crew? Five men do not constitute a crew, I believe, between the solid coal in place and the coal on the side track ready for the main haulage motor.

*Assistant to President, Hillman Coal & Coke Co., Pittsburgh.

Mr. N. A. Newdick: There are two men in the cutting crew, generally. They operate their cutting machine from place to place. It is mounted on a truck and cuts in a circle. There are two men in the shooting crew, the shooter and his helper. They do their own boring, charging and firing. Following them are the slate men. The number of these men will vary with the amount of slate they have to handle. They take the slate off the coal and gob it.

Mr. W. L. Affelder: What would you consider an average number of slate men?

Mr. N. A. Newdick: An average would vary from three to five. It is not the quantity; it is the kind of slate. After those will come two or three track men; two more often than three. After that comes the loading crew of five men, and two motormen and two brakemen with the gathering locomotives. Where the track arrangements happen to be just right, cars can be changed quite rapidly with a single locomotive, but that is the exception rather than the rule. The full crew consists of about 17 men. We have had cases where getting that same tonnage would take 25 men, but that is very rare, and 17 to 20 will cover 90 per cent. of all the crews. That may possibly not be true now, since they are working those machines under such bad roof. The average might be nearer 20 than 17.

Mr. W. L. Affelder: Do all those motors work on a day basis?

Mr. N. A. Newdick: Yes.

Mr. W. L. Affelder: What is the Pocahontas rate at present?

Mr. N. A. Newdick: I do not know.

Mr. W. L. Affelder: It changes very rapidly, and I do not know myself what it is at present.

Mr. Graham Bright:* You mentioned the two smaller motors that seldom operate beyond the first notch of the controller.

*Consulting Engineer, Howard N. Eavenson & Associates, Pittsburgh.

Have you ever considered putting in smaller motors and installing a higher gear ratio and running near the full speed of the motors—in other words, put on smaller motors and work them at full speed?

Mr. N. A. Newdick: Yes, and there is a reason why we do not. The space available for the motors is so shaped that we could get the motors in where we could not get the gears. The motor is out of proportion to the power demand, but that is the reason we do it that way.

Mr. J. W. Paul:* In some parts of the Pocahontas field there is a rather persistent binder of varying thickness in the bed. In hand loading most of that is rejected by the miner. I would like to know if that is rejected with the machine loader.

Mr. N. A. Newdick: Yes, outside the mine.

Mr. W. L. Affelder: Involving how much of an increase in tipple crew?

Mr. N. A. Newdick: We never had that mentioned, but since they have the preparation crew there anyhow I doubt if there is any increase in it. I have never heard that commented on, though. The Pocahontas Fuel Company has checked this machine and the maintenance and performance of the machine so closely that I think if there were any trouble or additional cost resulting from the use of it we would have heard about it, and I never have. That is the best answer I can give.

Mr. W. L. Affelder: I asked that question because most operators who have had experience with loading machines have reached the conclusion that where a mine is partially on hand loading and partially on machine loading, the introduction of loading machines in one section of the mine has materially increased the refuse in the coal in the entire mine, due to the fact that the men say that if dirty coal from the loading machine can be handled on the tipple, dirty coal from the hand loaders can be taken care of. I think there

*Mining Engineer, Pittsburgh Experiment Station, U. S. Bureau of Mines.

are several men present who will bear out that statement. With but a single loading machine handling only 10 per cent. of the output, the amount of dirty coal is very materially increased. I think Mr. Cameron can bear me out in this statement.

MR. A. P. CAMERON: No, sir, I should not like to be quoted. I am here to learn. This is a wonderful machine, working on paper or on the screen. I doubt very much if under certain conditions such as we have it would give such wonderful results.

The speaker did not mention timber or post men. Does he know what is the average loading in the Pocahontas field per day for hand miners?

MR. N. A. NEWDICK: About ten tons.

MR. A. P. CAMERON: You have 17 men loading 276 tons, or 16 tons per man per shift?

MR. N. A. NEWDICK: Yes.

MR. A. P. CAMERON: Does that include all the extra men? You ought not to add the gathering men and motor men to the crew. They are a part of any crew that would handle the same amount of coal.

MR. N. A. NEWDICK: That is only another instance of where the machine has been loaded with every possible cost they could put on it and it has come out to whatever extent it has come out. Even the cost of the tamping bags the shooters use is charged in.

MR. A. P. CAMERON: Our experience is not very extensive along that line. We have not found loading machines very successful working under our heavy draw slate and other conditions which we have to overcome, but probably we have not made as full a study of loading machines under certain conditions as your company has.

MR. N. A. NEWDICK: What is the particular difficulty you face?

Mr. A. P. Cameron: Draw slate above the coal and slate bands in the seam.

Mr. N. A. Newdick: Draw slate in the seam complicates the situation. That would be a very difficult matter to handle from the preparation standpoint, unless you could cut it out and use the impurities of the cut as the relief kerf into which to do the shooting.

Mr. A. P. Cameron: We have difficulty in shooting our coal so that the loading machine can handle it properly, or handle it at all without degradation.

Mr. N. A. Newdick: We are gradually finding out how, but it took us quite a while to learn.

Mr. A. P. Cameron: Do you think it is perfect now?

Mr. N. A. Newdick: No, sir, we know it is not. No sooner are we successful in one place, than in another part of the same mine it is necessary to vary the preparation; but it can be done.

Mr. A. P. Cameron: Is your draw slate, slate, or fire-clay?

Mr. N. A. Newdick: It is not fire-clay; it is hard clay and shale.

Mr. A. P. Cameron: Can it be held up with posts, or does it come down with the coal?

Mr. N. A. Newdick: It goes down with the coal. We never go under slate with the loading machine; we always take the slate out. It is a part of the procedure that is never departed from.

Mr. A. P. Cameron: Our draw slate is very friable; it breaks and falls down and mixes with the coal, and increases our ash percentage 8 or 10 per cent., and that is our greatest difficulty. If we shoot our coal hard enough to break the bands for the accommodation of the loading machine, we increase our slack percentage about five per cent.

MR. N. A. NEWDICK: Would it be possible to cut out those bands of impurities?

MR. A. P. CAMERON: It is possible, but it would increase the cost.

MR. N. A. NEWDICK: How thick is the coal that is left?

MR. A. P. CAMERON: About 18 or 20 inches, and we have a very friable material overlying the draw slate.

MR. N. A. NEWDICK: We have that same condition. We carry a double line of posts behind the machine all the time—each side of the track between the track and the rib—and then we set timber posts within 12 feet of the face.

MR. W. L. AFFELDER: When do you expect to have machines operating with flame-proof motors? Some of us are very much interested in loading machines, both for loading rock and coal, but until we can get a machine that will be passed by the United States Bureau of Mines our hands are tied.

MR. N. A. NEWDICK: The last time I was in Pittsburgh I went out to the experiment station of the United States Bureau of Mines and had quite a conference on the subject with their electrical engineer, and I am now in communication with a storage-battery manufacturer and I have about arranged to buy all the loading equipment our machine requires. I leave to-morrow for Schenectady to take up the question of flame-proof motors, and I intend to talk with the Westinghouse people. I imagine if we have pretty good luck, flame-proof motors are not very far off.

MR. T. G. FEAR:* With the average tonnage of 300 tons, and cars holding three tons, that means 100 cars a day. With two motor crews can that not be increased? That is just about one-half their capacity.

*General Superintendent, Inland Collieries Co., Indianola, Pa.

Mr. N. A. Newdick: Yes, it can be increased and frequently is increased. The normal loading is 300 tons or 100 cars, but that is not the limit. Up to the present time we have not found any better way to do it and maintain the flexibility of operation which we find necessary. For instance, frequently the working places you think are ready for the next day's work are flooded out over night and you have to go elsewhere to get the tonnage while that water is being pumped out. The main essential of success is to get the coal where you can get it. As you say, it is not a full day's work for a gathering locomotive.

Mr. T. G. Fear: One motor crew should be charged to the machine itself.

Mr. N. A. Newdick: We charge both of them.

Mr. Julian Kennedy, Jr.:* What is the average height?

Mr. N. A. Newdick: Most of our coal is nearly seven feet. Our machines are built to load successfully in 4½-foot seams. That is the lowest we have operated successfully. We have provided 12-inch lump clearance in a four-foot seam, but the lumps are so much larger than that, that 12 inches is hardly sufficient.

Mr. C. E. Lesher: Are the motors accessible?

Mr. N. A. Newdick: Two of them are. One is not, and it is the only motor on the machine that we have never been called on to repair. It is a Westinghouse motor. We have never had to move it, but if it was necessary to move it it would require the lifting of the gathering machine to get to the motor. It is the propeller.

Mr. C. E. Lesher: How long would it take to get it out?

Mr. N. A. Newdick: You could take the gathering conveyor off and lift the motor out of position in an hour.

*Consulting Engineer, Pittsburgh.

MR. H. M. ERNST:* Wouldn't your machine operate without that? Don't they shift the machine with one of the gathering motors in most cases?

MR. N. A. NEWDICK: Yes, but that self-propelled motor is not used to propel the machine; it is only to move the machine into the work. The machine is always moved from one place to another by the gathering locomotive. It would take too much time to do it any other way.

MR. GRAHAM BRIGHT: I think the men here would be interested in knowing something about the record of delays over a year's time on a large number of machines. Most of the coal loaders in operation to-day have a poor record in regard to continuity of operation.

MR. N. A. NEWDICK: During 1924 the total delays per shift due to machine failure or failure of electric equipment or all failures chargeable to the machine itself, was 9.18 minutes per shift. That is the total number of shifts divided into the total time lost due to machine failure.

MR. W. L. AFFELDER: How much clear face must there be between the face of the coal and the nearest timber?

MR. N. A. NEWDICK: To start with, 12 feet is plenty. It will be more than that after you shift the coal, but the prop ought to be at least 12 feet and let the coal come out to that prop. If that prop were set too near the center of the track where the machine starts, it might be necessary to take that timber out while you loaded the first edge off the pile, and then put it back again.

MR. W. L. AFFELDER: How do they do in the room places, gob it on one side or both?

MR. N. A. NEWDICK: On both sides.

MR. W. L. AFFELDER: How do they recover the ribs?

*Engineer, Pittsburgh Terminal Coal Corporation, Pittsburgh.

Mr. N. A. Newdick: Remove that slate.

Mr. W. L. Affelder: And relocate the track over next to the rib?

Mr. N. A. Newdick: No, they do not move the track; they just turn off from that track that is in the center of the room.

Mr. F. B. Dunbar:* What is the objection to putting the slate all on one side?

Mr. N. A. Newdick: I have often wondered that myself.

Mr. P. A. Young:† Have you any figures on the cost of maintenance per ton of coal?

Mr. N. A. Newdick: During 1924 the cost of repair parts was three cents a ton, and the cost of labor to install repair parts was 0.5 of a cent—a total cost for repairs of 3.5 cents. But it is hard to tell how long the machine will last. The frame and the main parts would never wear out. Most of the shafts would probably never wear out. The bearings are all renewable. Repair parts consist principally of gears, pinions and chains.

Mr. P. A. Young: Is all this coal cut with machine, or do you cut before it is shot?

Mr. N. A. Newdick: It is all cut before it is shot.

Mr. W. W. MacFarren:‡ Is part of the slate gobbed on one side of the room and part on the other?

Mr. N. A. Newdick: Most of the time.

Mr. W. W. MacFarren: And then when you come to rob the ribs you move it from one side and put it on the other side?

*General Superintendent, Hillman Coal & Coke Co., Pittsburgh.
†Mechanical Engineer, Duquesne Light Co., Pittsburgh.
‡Mechanical Engineer, Pittsburgh.

MR. N. A. NEWDICK: We have caught them doing it that way, but it is not recommended.

MR. M. D. COOPER:* Is there any mine from which the entire output could be produced by the machine, or is it always a combination of hand loading and machine loading?

MR. N. A. NEWDICK: There are now three mines at which the entire output is from machines. It is only when the property is all on a mechanical loading basis that the benefits of machine loading are apparent. When we are able to do that, the direct saving in cost as compared with hand loading is the smallest part of the advantage of mechanical loading. That does not become apparent until you have a property entirely on a mechanical basis where you can charge everything against the machine and everything that comes out of the mine is credited to the machine. It very much simplifies the accounting, and it is then that you find out the real benefits of mechanical loading.

MR. W. L. AFFELDER: What is the difference in the complete cost of coal from mines completely equipped with loading machines as compared with mines in the same district entirely on hand loading?

MR. N. A. NEWDICK: The saving will vary with the different mines because of the differing conditions in those different mines, but it runs from 25 to 35 cents, all mine cost. As I said before, that is really the smallest part of the advantage.

MR. F. B. DUNBAR: Is the force of the machine produced by the traction of the wheels or by rope and jacks with motor which is the method used in treating the standard mining machine.

MR. N. A. NEWDICK: The jacks produce no effect on sumping the machine into the coal. That is entirely by the tractive effort of the machine on the track—soft steel wheels on soft steel tracks.

*Assistant General Superintendent, Hillman Coal & Coke Co., Pittsburgh.

MR. B. H. KERSTING:* Is the required crowding effort to force the machine into the coal exerted by the propelling mechanism and track wheels, or by the previously mentioned jacks, and what function have these jacks? Are the soft wheels and rails to be preferred to the ordinary high-carbon steel rail and wheels?

MR. N. A. NEWDICK: Yes. We use the ordinary standard room track to go in on, but when the machine arrives at its working place it runs off that rail on to an extension track. When the machine is still on the regular rail track it meets very little resistance in going into the coal and the tractive effort is sufficient; but when it gets into the coal far enough to meet much resistance all four wheels are running on this extension track and then we get our maximum tractive effort on that combination of soft steel wheels and rails.

MR. J. M. RAYBURN:† Is it practicable to mount this machine on caterpillar treads?

MR. N. A. NEWDICK: Yes.

MR. H. N. EAVENSON:‡ The Carnegie Institute of Technology in co-operation with the United States Bureau of Mines is just finishing a study (Coal-Mining Investigations, Bulletin 17) on loading machines, and we hope to have the report in the hands of the printer and published either in June or July. Any one desiring a copy of that publication can get it from the Institute. There were 51 installations visited and described and I think about twenty-three types of machines were seen.

MR. C. M. LINGLE:§ I do not have any preconceived ideas about this, but I would like to know why they cut the coal in the middle with breast machines.

MR. N. A. NEWDICK: It works out much better than you might expect. One reason is that they get that cutting machine around from one location to another so rapidly that they have been able to save the shooting to such an extent that they can continue that practice.

*Mechanical Engineer, Dravo Contracting Co., Pittsburgh.
†Civil and Mining Engineer, Pittsburgh.
‡Consulting Engineer, Howard N. Eavenson & Associates, Pittsburgh.
§Manager, Buckeye Coal Co., Nemacolin, Pa.

Mr. C. M. Lingle: Then does the coal shoot free from the bottom? How much preparation is there to make for the cutting after the loading is completed?

Mr. N. A. Newdick: None at all. The loading is perfectly clean. The cutting machine could follow the loading machine within thirty seconds if it were there to come in. That is one thing that the man on the front end of the loading machine does. His presence is necessary at the last of the cut very much more than at the first of the loading. When you get to the back of the cut there is always one foot to 18 inches of coal that hangs and does not come down, and he takes that down to the solid coal.

Mr. C. M. Lingle: Do you have any hanging shots similar to those in the Pittsburgh seam where it does not crumble and all roll down into the machine or just settle down?

Mr. N. A. Newdick: That is what we try to get it to do—to settle down on the machine. If it is too hard, it does not pay to bother with it; the machine is taken to another place while that place is shot again.

Mr. C. M. Lingle: You spoke of two motors. Does one handle the loads and the other the empties?

Mr. N. A. Newdick: No, each gathering locomotive will take about four cars at one trip and push the end car of the trip under the loader, and when it is loaded pull it out and run down the room track and kick it into a break through. The other gathering locomotive is standing farther down the room with its four cars; and, as soon as the first pulls out, the second takes its place. If there were not two available, one would run back with his load on the end of his trip and push it on to the break through track and cut it off and bring back his three empty cars, and when he had loaded the four cars the machine would have to wait until he took those cars out and placed them and got four empties and came back.

MR. JESSE K. JOHNSTON:* I desire to say that the day of mechanical mining has arrived and, for your information, it is a waste of time to place in charge of mechanical mining or modified long-wall system of mining, any man who is either antagonistic or prejudiced, or has a passive resistance to modern mining methods. The right kind of man to take charge of mechanical mining and modified long-wall system is one who believes it can be worked successfully and economically, as this is 90 per cent. of the battle. One former of modern ideas who gets results is worth a thousand reformers with visionary ideas.

The McCormicks who invented the harvesting machine worked for twenty-four years before they succeeded in getting a machine that would cut grain standing up, matted lying down, and on level as well as on hilly ground.

Sixteen years ago, at Creighton mine, I experimented with one of Joseph Leiter's coal-loading machines which he worked at the Bell and Zoller mine in Illinois in an attempt to break the union, but the union won the fight and I secured the loading machine at a low rental.

The loading machine was all right in principle, but it was too heavy and cumbersome to move around from one working place to another; and, while it loaded coal in a satisfactory manner, it moved around the face of the room in a semi-circle and left coal in each corner of the room which had to be shoveled by hand before the place could be undercut. So you see the coal-loading machine has been going through the same rate of evolution as the harvester, but in all these years I have always believed that the obstacles and difficulties in Joseph Leiter's loading machine would be overcome, and I am glad to say that we have mechanical loading machines to-day which will load coal successfully at 40 cents a ton lower than by hand loading.

Mr. Newdick has been very fair in representing the number of men operating the "Coloder" mechanical loader. If you simply want to compare this machine with the undercutting and hand loading, you must eliminate the motorman and helper and trackman, for the reason that this labor is required in any system of mining.

I have examined a number of mechanical loaders working under favorable conditions, and in some mines the machines are not loading

*President, Ridgeview Coal Co., Bolivar, Pa.

50 per cent. of the capacity of the machine, due to the fact that the mine-cars are not delivered promptly to the face of the workings. Estimating the amount of coal undercut and shot down, a run-around track can be installed in the working place holding the number of mine-cars required for the amount of the undercut coal, and by the use of a room hoist the empty cars can be delivered to the mechanical loader as fast as the mine-cars are loaded.

I have always favored the introduction of a mechanical loader in a new mine where it is possible, as this will place the loader on its own merits and do away with prejudice and antagonism to a large extent. I would suggest to any operator who is considering mechanical loaders to visit mines where the mechanical loaders are working, so that he can determine whether his conditions are suitable for mechanical loaders.

The claim is made that mechanical loaders make more slack than hand loading. I think this can be overcome by careful shooting of the coal.

The question arises, is vertical cutting in rooms and entries economical? Personally, I think vertical cutting loses more money than it saves. While it may reduce the powder cost per ton more than 50 per cent., the percentage of slack produced in places only 12 to 14 feet wide is more than doubled, and is greatly increased even in full-width rooms. One of the great advantages of mechanical loaders is the rapid development of working places as compared with the hand loading. I know of one mine where mechanical loaders are used where five times as much entry was driven in one month as by hand-loading methods.

The question is asked, if the loader could be supplied with all the mine-cars he could load in eight hours, what would be the average tonnage per loader?

At the Norton mine of the West Virginia Coal & Coke Company, the Lower Kittanning seam of coal is worked by the modified long-wall system and conveyors. This seam has a binder similar to the twin-seam Freeport in Allegheny and Westmoreland counties. Eliminating the binder, about 5½ feet of coal are mined. It is simply a question of shoveling coal into the conveyor, and this class of labor averages about 25 tons to the man.

At mines where the room-and-pillar system is worked with the same height of coal, under similar conditions, allowing for the delays in delivering mine cars to the loader, the average per loader is about 10 tons. Efficient loaders will load as high as 20 tons, but the average of 10 tons I think is fair. The "Coloder" mechanical loader, according to Mr. Newdick, will load an average of 275 tons to the shift with one operator and two helpers.

MR. N. A. NEWDICK: Mr. Johnston did not quite get what I meant about not getting the full benefit of the machine until the mine is on a full mechanical basis. I did not refer to opening up a new property. That would, of course, be the ideal proposition; but all the work that "Coloders" have done in the Pocahontas field has been done in developed properties. The job was to develop a machine that would take a mine as we found it, and load coal; and the only change we have ever made was to get a considerably better track (but not as good as we ought to have) and a little larger mine-car. If the seam is clean and the roof is reasonably good, you can put mechanical loading in an old mine. The point I am making is that these machines have been developed and used successfully in old mines.

MR. P. A. YOUNG: How long does it take to change the cars with these two motors?

MR. N. A. NEWDICK: Many cars are changed in 30 seconds, yet time studies, hundreds of them, show that the best average we can strike is about 1 1/3 minutes for changing a car.

MR. F. B. DUNBAR: Are they storage-battery locomotives?

MR. N. A. NEWDICK: No. Cable-reel locomotives.

MR. W. L. AFFELDER: Don't you have trouble with cables getting tangled up and with motormen running over each other's cables?

MR. N. A. NEWDICK: No, because one is passing down in the room and the other is up at the break through. At the time when the two are nearest together is the only time the cables could become entangled, and I do not recall that I ever saw that happen.

Mr. F. B. Dunbar: Have any figures been prepared showing what the miner or coal loader would do in tons per day, if given the same chance the machine is given. I feel that if the miner were given the same privileges as the machine, in that he could load any material at the face, whether slate or coal, without preparation, and that someone set the timber for him, laid his track, drilled the holes and did the shooting, the miner would increase his production to about thirty tons a day.

Mr. N. A. Newdick: I do not know. I do not think I have had enough experience in mine operation to have an opinion on that.

Mr. H. N. Eavenson: I understood you to say the men average about 17½ tons a shift. The Pocahontas seam is a much dirtier seam, and they do not get their cars changed in thirty seconds, either.

Another point which those not familiar with the Pocahontas field do not realize is that, in that territory, the range between the price of slack and the price of lump is about $2 a ton and, where their coal is shipped as screened coal, that difference in the amount of screened coal means a very considerable difference in the price per ton, so the machine must be doing pretty well in producing lump coal, or it would not pay to use it at all.

Mr. W. L. Affelder: It depends on the mine. We have a mine with coal 7 to 7½ feet thick where the mine-car holds less than three tons. Year in and year out that mine averages between 18 and 19½ tons per face man per day; and 160 loaders will load 3000 tons of coal and do it every day without any mechanical loaders.

Mr. A. P. Cameron: In our Pittsburgh district where coal is hard to shoot (on account of the slate bands), and where slack is a factor, it is shot with as little powder as possible in order to reduce the percentage of slack. What would your loading machine do when a five- or six-foot vein of coal settles down the thickness of the kerf in a solid block; would it undermine and load out this block in such a manner that the slack percentage would not be increased over that of ordinary loading?

Mr. N. A. Newdick: It is shaken up and full of cracks, so if it is disturbed it will separate into lumps of 500 to 800 pounds.

Mr. A. P. Cameron: You mention 3½ cents as the cost of repairs. How much would that increase the cost of repairs as compared with soft lump coal?

Mr. N. A. Newdick: I do not think it would increase the repair cost at all. It would increase the number of bolts used in those arms. That is the weakest link between the power supply and the coal. If it could not pull the coal apart it would break off two or three arms. I have seen that happen when the coal jammed or when the arms came in contact with the rib. But when an arm breaks off you have only lost one ⅞-inch bolt. I have seen the machine go into Pocahontas coal that seemed to be hardly powder shaken at all. That is the basis for my statement.

Mr. A. P. Cameron: Are these loading machines now being put on the market?

Mr. N. A. Newdick: Yes, sir; they are just now being put on the market.

Mr. W. W. MacFarren: I had the pleasure of listening to Mr. Newdick's paper and the discussion thereof and was on the point of bringing out some circumstances relating to the development of the "Coloder," with which I am quite familiar, but hesitated to take up time among so many interesting speakers. However, I think there is a lesson to the whole mining fraternity—the operators in particular—in the following circumstances:

This machine is the invention primarily of Mr. James E. Jones, of the Pocahontas Fuel Company. For a long period Mr. Jones tried to produce a practical loading machine for his mines. I believe this effort extended over a length of about twenty years. Probably fifty patents were taken out, and some of the early ones had expired before the first successful machine was developed.

Now, whatever we may think of this machine for use in any certain mine, the fact is, that it holds the world's record for total

production, and the least that can be said of it is that it is one of the best two machines yet produced for the purpose, the other being the Oldroyd loading machine.

Mr. Jones is now advantageously situated. He has wonderful coal and 22 loading machines good for a daily tonnage per single shift of about 6000 tons. This is in a non-union district, and the machines suit his conditions.

I have heard it stated that $300,000 was spent on the development of this machine. What of it? Last year's tonnage loaded by machines was 1,500,000 tons, and figuring a saving of only 25 cents a ton—a low figure for these mines—they got it all back plus 25 per cent. in a single year. If these 22 machines cost the company $15,000 apiece to build, they will get their entire cost back in another year. The moral is that the people who are to derive the major benefits must take the major risks. The development work should be done by the operators, either singly or in a pool. The manufacturer of machines or the inventor of such machines makes one moderate profit and is done. Under present conditions—especially in the Pittsburgh district—machines for cutting and breaking down, for loading simply, and for cutting and loading combined, can be developed in a comparatively short time and at nominal expense, and which, for each month of operation, would show a profit to the operator, equal to the whole profit per machine to the manufacturer.

If the Pocahontas Fuel Company has an advantage over some of the Pittsburgh operators, whose fault is it? Why should West Virginia have any *mechanical* advantages over Pittsburgh?

THE UNIVERSITY OF PITTSBURGH STADIUM*

By W. S. Hindman†

The need for an adequate athletic plant has long been evident at the University of Pittsburgh, and each year the situation has become more acute. The athletic teams have been compelled to use rented grounds on which to play their exhibition games in all branches of sport and it was decided last year to proceed with the construction of a new stadium. This structure is now being built and it is expected to supply their needs in this line for many years to come.

To the casual observer these great structures do not signify their real meaning. The superficial impression of a great stadium may be expressed in terms of thousands of spectators, but to the student the great structure represents the climax of his school's recreational activities and the show place for himself and for those of his fellows who happen greatly to excel in any one branch of athletic endeavor. The great structure at any institution is the climax of its athletic system, the acropolis of athletic inspiration, the typification of a great ideal which spurs each student on to do his best in his own recreational pursuit.

After making a careful survey of all the available property in the Schenley district on which a stadium might be constructed, the present location was selected for the reason that it seemed to satisfy most of the requirements—the desirability of being located on the University campus, non-interference with other University buildings, reasonable cost of construction, due to land values and natural contour of the ground, and accessibility from the main arteries of transportation.

The stadium is located at the head of De Soto Street and is convenient to Fifth Avenue, Forbes Street and Centre Avenue, which are the main arteries of traffic through this district. A survey of the entire district shows that it is possible to park about 14,000 automobiles on paved streets within a radius of five-eighths of a mile from the stadium. No parking will be permitted on streets adjacent to the stadium on account of interference with, and danger to, pedestrians.

A careful study was made to determine what type of structure

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†Chief Engineer, Pitt Stadium Committee, University of Pittsburgh, Pittsburgh.

would best fit into this location to give a pleasing effect from an architectural standpoint, and accommodate as many athletic activities as possible. There are, generally speaking, three types from which to make a selection; namely, the open-end type, such as those at Harvard, Princeton, and Ohio State University, which are built entirely above the natural ground level on structural framing to support the seats; the bowl type, such as at Yale, for example, where a great hole has been excavated and the dirt piled up around the edges and the seats constructed on the slope; the closed type, where a portion of the hillside is excavated and the seats placed on the slopes, while the low or downhill side is supported on framework. The first two types mentioned are suitable for level ground, but the last type was selected here.

The site selected, being in the background of the group of fine buildings in the Schenley district, permits the use of concrete for the exterior and we have used a very simple architectural treatment for the exterior.

The so-called architectural embellishments are very few, as we have considered it as a massive structure and attempted to give a pleasing effect by proportioning and placing the exterior openings to have good lines. Only one entrance, on the east side, has been featured, by having a huge arch and projecting it out from the exterior wall. The entire architectural treatment has been fitted to the interior lay-out, so that there is no lost space, thus giving the most economical design. We have indicated on the drawings the way the contractor shall build his forms with all form boards running vertically. At 10-foot intervals there is a four-inch horizontal band, and concreting can be stopped at the top of any of these bands. The band hides the construction joint in the concrete and gives a paneling effect to the walls. The concrete is left as it comes out of the forms, which gives it a good texture and will look better in a few years than if the surface had been treated in some way.

The stadium is intended to accommodate foot-ball, baseball, track athletics, basket-ball and other indoor athletic activities, besides being available for large public gatherings, pageants, etc. Provision has been made for the installation of flood lighting and amplifiers so that the stadium can be used at night.

The structure at present consists of a single deck and will accommodate approximately 70,000 spectators, but is designed so that a second tier of seats can be built and the capacity increased by 30,000. All sight lines have been carefully worked out and a good view of the entire field can be had from any seat. The structure is laid out on what is known as a three-centered oval or by using two radii. This makes all seat lines on a curve and causes the sight lines to radiate from a point in the field, thus giving a greater equalization of seat values than if the sides were straight. This enables a spectator to see the entire crowd in the stadium which we believe is good from the standpoint of crowd psychology. In order to shorten the stadium on the long axis we have cut the quarter-mile track into the seat banks at the ends, which eliminates the low undesirable seats at these points. The main dimensions are, length overall, 791 feet; width overall, 617 feet; length inside, 563 feet; width inside, 343 feet; height of lower deck above playing field, 60 feet; and greatest height outside, 105 feet, which will be increased to 135 feet when the upper deck is built.

The interior circulation problem was very difficult to solve since the entrances are from an elevation 35 feet below the field level to 60 feet above. The structure was first divided into 36 equal sections measured on the outside perimeter, and each of these sections is fed by an entrance through a portal or from a doorway at the top of the seat bank. There are 21 sections fed directly from the street level and 15 by means of portal entrances from a large circulating or distribution gallery under the stands. There are five large entrances leading to this gallery. Two of these lead directly onto the gallery, while the other three reach it by means of large ramps. The estimated time for discharging the entire crowd from the lower deck is 15 minutes.

The stadium is built almost entirely of reinforced concrete and structural steel. The structural steel is entirely on the inside and is used to support about one-half the seat banks. The use of structural steel in the high part was resorted to to facilitate construction, since it could be erected in the winter time and is slightly more economical than concrete framework. Approximately half the seats are poured directly on the slopes, but are designed as a flat-slab construction, so that in case the ground should settle away the structure would not be damaged. After construction had started, it was discovered that

almost the entire area resting on the slopes was undermined by old coal workings and in very bad condition; also we knew that a mine fire was burning under the adjoining property, so it was decided to extend the supporting caissons to a point below the bottom of the coal seam. This has been done, and the caissons are fireproofed at the bottom through the coal by surrounding them with granulated furnace slag having a minimum thickness of two feet. All foundations have been carried to solid rock.

The seats consist of three redwood strips fastened to malleable iron brackets, which are attached to the concrete risers by means of galvanized bolts screwed into inserts which are placed when the concrete is poured. The box-seats will be individual folding chairs, and each box will have eight of these chairs.

In most stadiums previously built, little attention has been paid to supplying adequate toilet facilities, but we have given this point serious consideration and we believe that this stadium will be better equipped in this respect than any previous one in this country. There are 20 public toilets, not including those for the team quarters.

Provision has been made for both the home and visiting teams. The home-team quarters, for example, include locker rooms, showers, toilets, drying rooms, trainer's office, doctor's office, rubbing rooms, lecture-room, coach's office and manager's offices.

The basket-ball room has a seating capacity of 5000, is steam heated and has independent locker room and shower room.

The playing field is shaped as a turtle back with 18-inch crown in the center, has lines of four-inch drain tile spaced 15 feet centers, over which is placed five inches of coarse gravel, three inches of fine gravel and 10 inches of top soil mixed with 20 per cent. of granulated slag. The furnace slag was used to loosen up the soil and give it greater porosity.

All concrete in the superstructure is mixed at a central mixing plant and distributed by means of an industrial railway laid around the top of the structure. The concrete is hauled from the mixing plant in concrete hopper cars and deposited through metal chutes.

For a number of years the writer has been interested in methods of securing better concrete, and since some similar structures have caused much trouble due to poorly proportioned, mixed, and placed concrete, we were particularly anxious to get the best possible results

on this stadium. An extensive research has been carried on at the Lewis Institute in Chicago for a number of years under the direction of Mr. Duff A. Abrams, and much has been learned about the proper proportioning of concrete materials and the effect of water on the strength of concrete; therefore, it is generally known that engineers can now design concrete mixes which will give the required strengths, provided the proportioning can be done accurately. It is a well known fact that sand will bulk from 25 to 30 per cent. when it contains from three to eight per cent. of moisture above that when dry. The inundation method of measuring sand (invented by Mr. Escher, president of the White Construction Company, New York, and used by that company) has overcome much of this difficulty. The Blaw-Knox Company is now manufacturing the sand inundator, which has been greatly improved as to mechanical operation, and we had the first one installed on this job in conjunction with the Blaw-Knox hopper for measuring the coarse aggregate. The whole plant is very compact and easy to operate, and is giving very satisfactory results. It is the only plant the writer has seen which will give accurate measurement of materials and produce a concrete of uniform consistency.

The following are a few of those connected with the project:

General design, plans and specifications, prepared by W. S. Hindman; Stone & Webster, Inc., supervising engineers on construction; Turner Construction Company, general contractors on superstructure; McClintic-Marshall Company, fabrication and erection of structural steel; John F. Casey Company, general grading and concrete foundations; New England Foundation Company, represented by the Simplex Pile Company, of Pittsburgh, Gow concrete piles.

In conclusion, I think the following is very fitting to this project. Great opposition to the site was expressed in unbridled terms; but, as the clouds cleared and the beauty of the project was revealed, criticism has given place to commendation and anathemas have been forgotten. The stadium project has suffered untold ills; it has been subjected to repeated critical investigation; it has been decried, condemned, cut, slashed, changed, moved, and delayed—and still it survived and grew and will soon be completed. It challenges the admiration of the world as an architectural monument and engineering achievement ranking with the greatest of all times.

THE TURNING POINT IN COAL*

By C. E. Lesher†

When a ton of soft coal can be bought at the mines for $1.30, why pay more? All over the States of West Virginia and Kentucky, and in parts of Pennsylvania, mines are pouring forth thousands of cars of coal each day, eager for a market, at prices ranging from $1.25 to $1.60 a ton; good coal for making steam, firing locomotives, melting iron or making coke. In the northern fields, where the United Mine Workers are in power, the Jacksonville wage scale holds the operators to a cost for labor alone which equals or exceeds the selling prices of the southern non-union coal.

This, in a word, tells the story of the present difficult situation in which the union fields find themselves. Of these union fields Pittsburgh is hardest hit. The majority of the mines here are closed and non-union coal is pouring into our markets. The conditions that have prostrated the commercial operators and vitally affect the industrially owned or captive mines are not the result of any sudden or precipitate action. They are the outcome of a long series of related events. It is rather that the situation has reached a climax—a crisis, if you will. In the economic warfare that has driven in the market frontiers of Pittsburgh district coal a turning point has been reached. Pittsburgh has its back to the wall.

The war-time demand for coal, the 1920 industrial boom and the coal shortage following the 1922 strike of nearly half a year all contributed to the expansion of the soft-coal industry. The easy profits of those unusual periods enticed much new capital into the mining game and the recurring shortage caused many large consumers, as steel companies and utilities, to open new large mines of their own. The high wages attracted thousands of men into the ranks of the coal-mine workers. A fuel-hungry country took all the coal the railroads could move in the first few months after the 1922 strike. Every operator had a chance to produce and sell at a profit until finally by the middle of 1923 stock piles were replenished and

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†Assistant to President, Pittsburgh Coal Co., Pittsburgh.

demand and prices dropped. The decline that set in then followed through 1924.

To-day, and for a year past, competition has ruled the soft-coal business. The pace was set early in 1924 by the non-union operators. The price of soft coal dropped a dollar a ton almost as soon as the urgent demand of 1923 was satisfied. As the price dropped, the non-union fields reduced wages and, by thus cutting costs, were able to stay in the game. The Island Creek Coal Company is the outstanding example of large-scale, non-union coal production. That company in 1923 produced 3,000,000 tons. By reducing wages and costs it was able to set a low price. Sales were nearly 5,000,000 tons in 1924 and have recently attained a monthly rate of 600,000 tons, or more than 7,000,000 tons per year. This is expansion with a vengeance.

While the union miners were on strike through nearly half of 1922, the non-union fields, eager and willing to meet the urgent demand of industry for coal, succeeded so well in expanding their capacity that they reached a weekly output of nearly 6,000,000 tons, hampered though they were by car shortage and with a portion of the non-union territory on strike. The expansion thus underway has proceeded so that to-day these non-union operations, mainly in the south, may easily produce 7,000,000 tons of soft coal a week; whereas, in the general strike of 1919, the union closed down 71 per cent. of the production of bituminous coal-mines, leaving less than 30 per cent. in operation as non-union; and cut production from more than 12,000,000 tons to less than 4,000,000 tons a week. To such an extent has the union lost ground and non-union mine capacity been increased, that to-day the unorganized fields can produce, not 30 per cent. of the required soft coal for this country, but more than 70 per cent.

Indeed, measured not in capacity but in production, the figures are even more striking. In May 1923, 47 per cent. of the soft coal produced was non-union; in May 1924, 54 per cent. was non-union; and in May 1925, the lower priced coal from the unorganized fields represented 70 per cent. of the total output of the country. Throughout 1924 the union producers sought to retain their trade; they produced coal at union wages and selling it at prices set by the non-union producers, took substantial losses. There is very little consuming

territory that the non-union mines cannot reach at freight rates but slightly higher than from the nearby union coals.

The bituminous coal industry is over-developed. It has had wide and rapid fluctuations in production. But the iron and steel industry, the rubber, automobile, and machine-tool industries, to mention but a few, are over-developed; they suffer from cyclic variations in output; they are subject to booms and depressions as is coal.

Viewing the bituminous coal industry as a whole—taking into consideration the many fields in the United States—it is well said that there can be no stability and no profits until the capacity is deflated; until thousands of operators and mines and hundreds of thousands of mine workers are eliminated. It would be a most satisfactory condition were there but mines and mine workers sufficient to produce say 10,000,000 tons of coal each week, and then that the demand could be so regulated that 10,000,000 tons would be produced each week throughout the year. That indeed would be ideal for thus capital and labor would both be regularly and completely employed. The anthracite industry has approximated that happy state, but only after a quarter century of struggle comparable to that now taking place in the bituminous coal industry and not until the entire undeveloped resources had been taken into ownership by the producing companies. How idle it is to anticipate such a solution in the soft-coal fields, vast and widespread as they are. There are now too many tons of coal ready to be produced and constantly offered, for any but the very favored few to realize a profit in the operation.

Yes, the bituminous coal industry is over-developed; it must be deflated but it can not be deflated to the extent or in the manner our great idealist in Indianapolis hopes. What is involved in wiping out over-development? How is deflation of coal-mine capacity to be accomplished? By the reverse of inflation, of course. Instead of adding mines and jobs for mine workers, it means subtracting mines and jobs from mine workers.

Closing a mine, discharging the men, shutting off air and stopping pumps does not, however, permanently subtract a mine from the list, for the mine may be reopened. Complete abandonment, destruction of the facility for production and writing off the capital invested is the only real method of deflation. No reasonable, thinking coal-man refuses to admit the logic of this. All know that some, many in fact,

must be forced out through sheer inability to compete. That is American business. But the competition for business, the struggle of the fittest to survive must be governed by rules of the game that will equalize the opportunity. Other things (such as quality of coal) being equal, it is cost of production and freight rates to consumers that fix the limits of competition. There is a fair tribunal before which the coal operator may take his questions of freight rates. There are very definite ways, certain well defined procedures that mark the settlements of freight-rate controversies. This tribunal, the Interstate Commerce Commission, has constantly before it the complaints of coal operators.

With respect to the other largest item in cost of putting coal to the consumer (the labor cost of mining), there is no such fair tribunal. In the non-union mines the wage is set by the price of coal, limited only on the bottom by the scale of living costs. In the union fields the wage is set by contract with one organization, the International United Mine Workers of America.

Within the non-union areas the process of elimination of the unfit, the deflation of the coal industry, is presumably proceeding apace. Some are falling by the wayside; but, on the whole, since the non-union fields with substantially lower costs are getting the major portion of the going business, they are in a stronger position than the union fields. Ability to compete—that is, cost of production—puts the union fields in a class by themselves. The union fields as entities are being eliminated. We thus come to the crux of the whole problem. We recognize the fact of over-developmnt; we know the only method by which that over-development can be reduced to such a reasonable point that those surviving may have hope of profitable operation of their mines; and we find that by reason of a fixed, inelastic, high wage scale in the union fields, these fields are marked for elimination by reason of that very fact. Let us now examine some of the evidence.

Fig. 1 illustrates the shrinkage of Pittsburgh district markets.

Twenty years ago Pittsburgh seam, Youghiogheny gas coal was the most widely known, standard, high-volatile coal in the United States. It was marketed by millions of tons down the Mississippi valley to New Orleans; it was used in St. Louis gas plants; it was sold through the Middle West and Northwest and throughout the

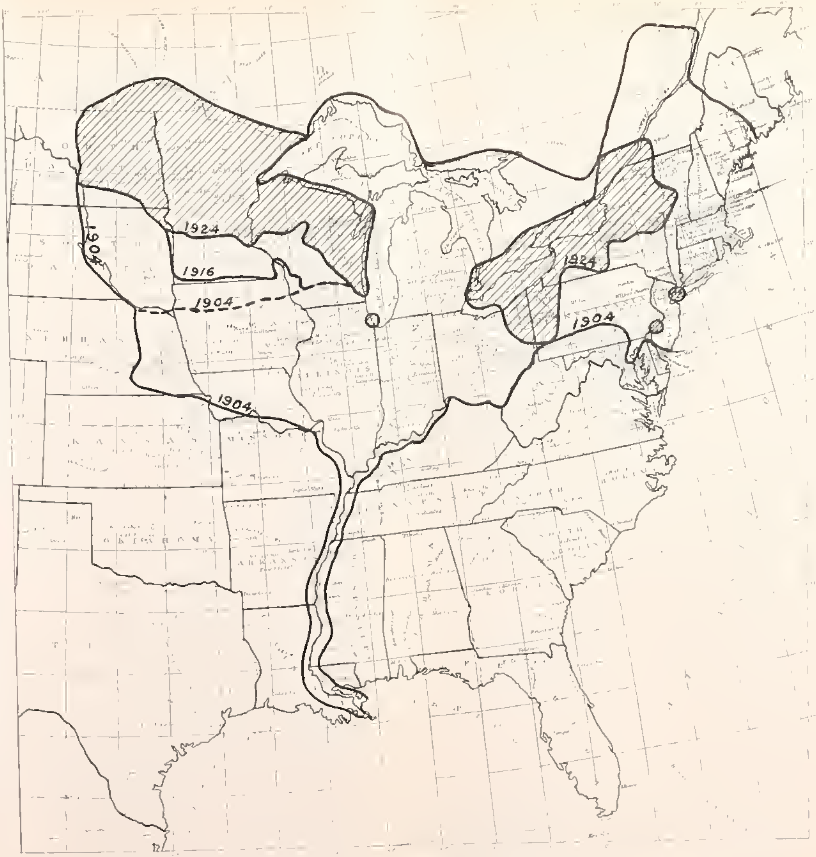

Fig. 1. Shrinkage of Market for Coal from Pittsburgh District.

East; it shared the New England market with Irwin basin gas coal from the same Pittsburgh seam.

Ten years ago, in 1914, the outside limit of the market territory for this coal was much the same, although decreasing proportions of the requirements of some of these markets were supplied from Pittsburgh. Subsequently, the lower river markets were conceded to non-union coals from Alabama, Kentucky and West Virginia. The New England coastal market was conceded to water-borne coal from Hampton Roads. All-rail, high-volatile, non-union coals forced back the line in the middle and northwest. Kentucky and West Virginia coal drove the frontier back through the lower peninsula of Michigan, Illinois, Indiana, and in Ohio to Cleveland. The line shown here for 1924 is not a solidly held line. Non-union coal is filtering through in every route. Coals of markedly lower quality, because of notably lower prices are being consumed in preference to Pittsburgh district coal in this residue of market area.

Fig. 2 shows comparative yearly percentage of capacity to produce (calculated from yearly production and average days worked) for those fields shipping into local, western and middle western markets. Expansion of Logan, eastern Kentucky, smokeless, Fairmont and eastern Ohio are contrasted with the contraction of southern Ohio, Pittsburgh and—to some extent, through exhaustion—of Connellsville. If this were carried forward to 1925 the expansion of the southern fields would be more marked.

Fig. 3 indicates how the Logan County, West Virginia, field expanded during 15 years up to 1920. The names of the producers as they came into production are shown with the accumulated tonnage for the field. Note the increase in number of operations in 1917 and 1918. Island Creek in 1920 was a little less than 2,000,000 tons. In 1924 it was 5,000,000 tons, so that one may easily picture the rate of vertical ascension that would be shown were the diagram brought to date.

Fig. 4 shows somewhat similar conditions for the Pocahontas Broad Top field.

Fig. 5 indicates the increasing output in non-union areas, for the period Jan. 1–May 31 for a series of years.

The strangest doctrine is being preached by the leaders of the miners' union. It is that there is no market for coal; that selling

price has no effect on marketing coal; in short, that the high cost of labor in the union fields has had no effect on the production of those

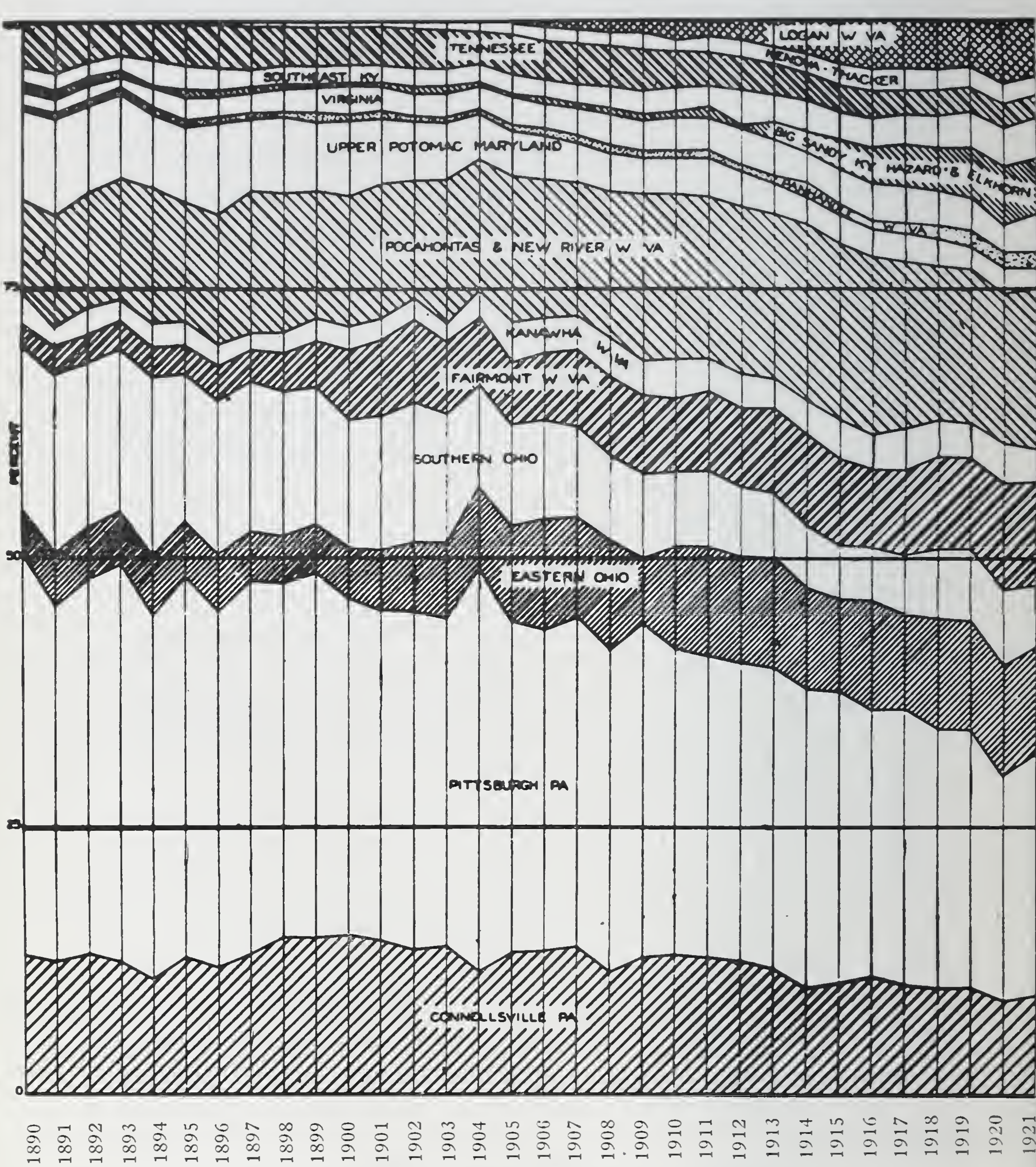

Fig. 2. Capacity of Eastern Fields, 1890-1921.

fields. They, in fact, are denying that the non-union coals are taking the markets of the union coals. They seek to pacify the idle members

of the union with the assertion that were they to accept the lower wage urged by the operators, they would even then have no work.

The diagram in Fig. 5 shows all too clearly what is taking place. The union States, Ohio, Illinois and Indiana, and Pennsylvania which

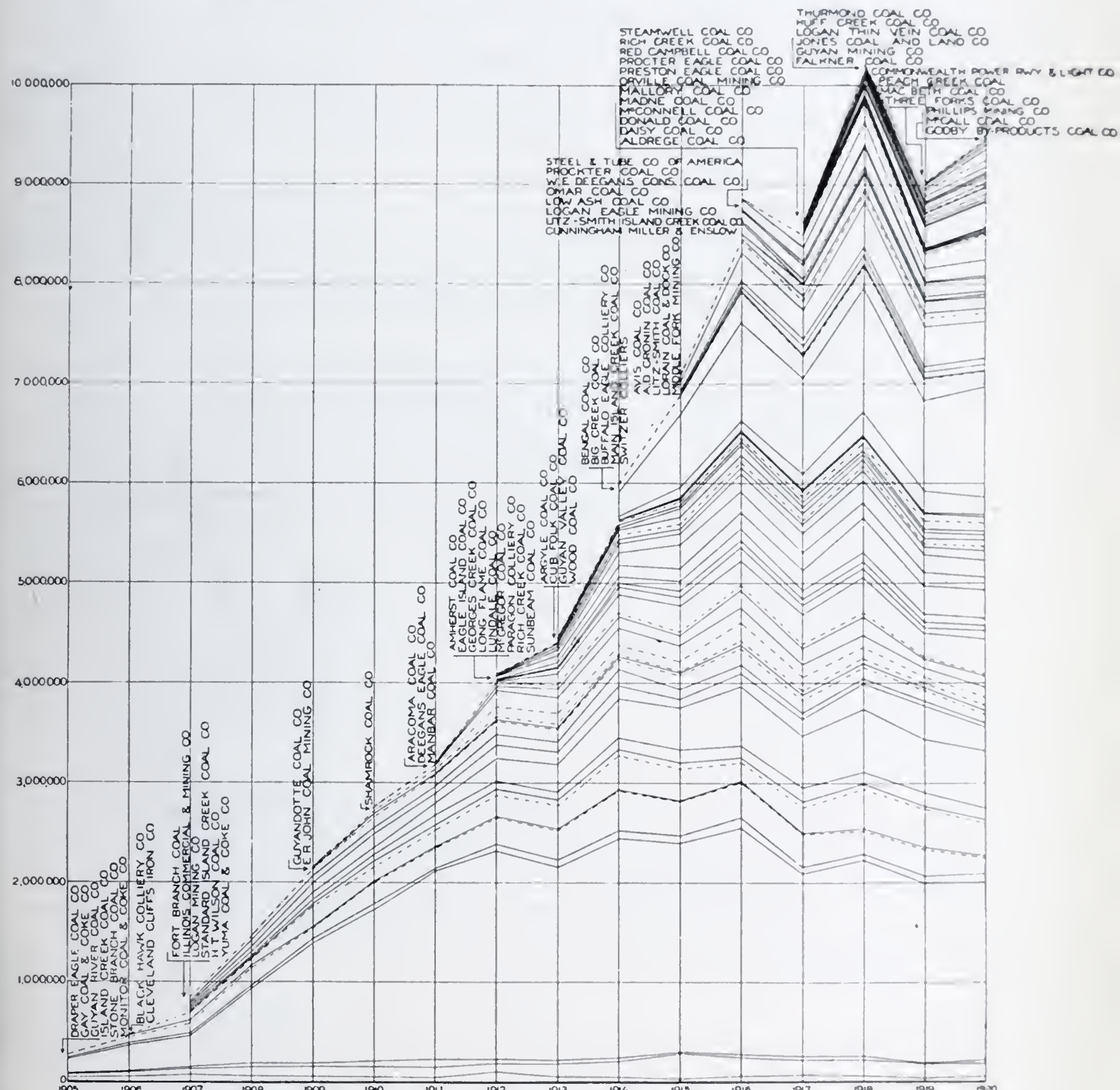

Fig. 3. Coal Production of Logan Field.

is only partly organized, are losing fast in the race for markets. Kentucky and West Virginia almost solidly non-union and with lower wage costs are gaining.

The record for three years is shown in another way in Fig. 6. Of the union States, Ohio, Illinois, and Indiana have responded to

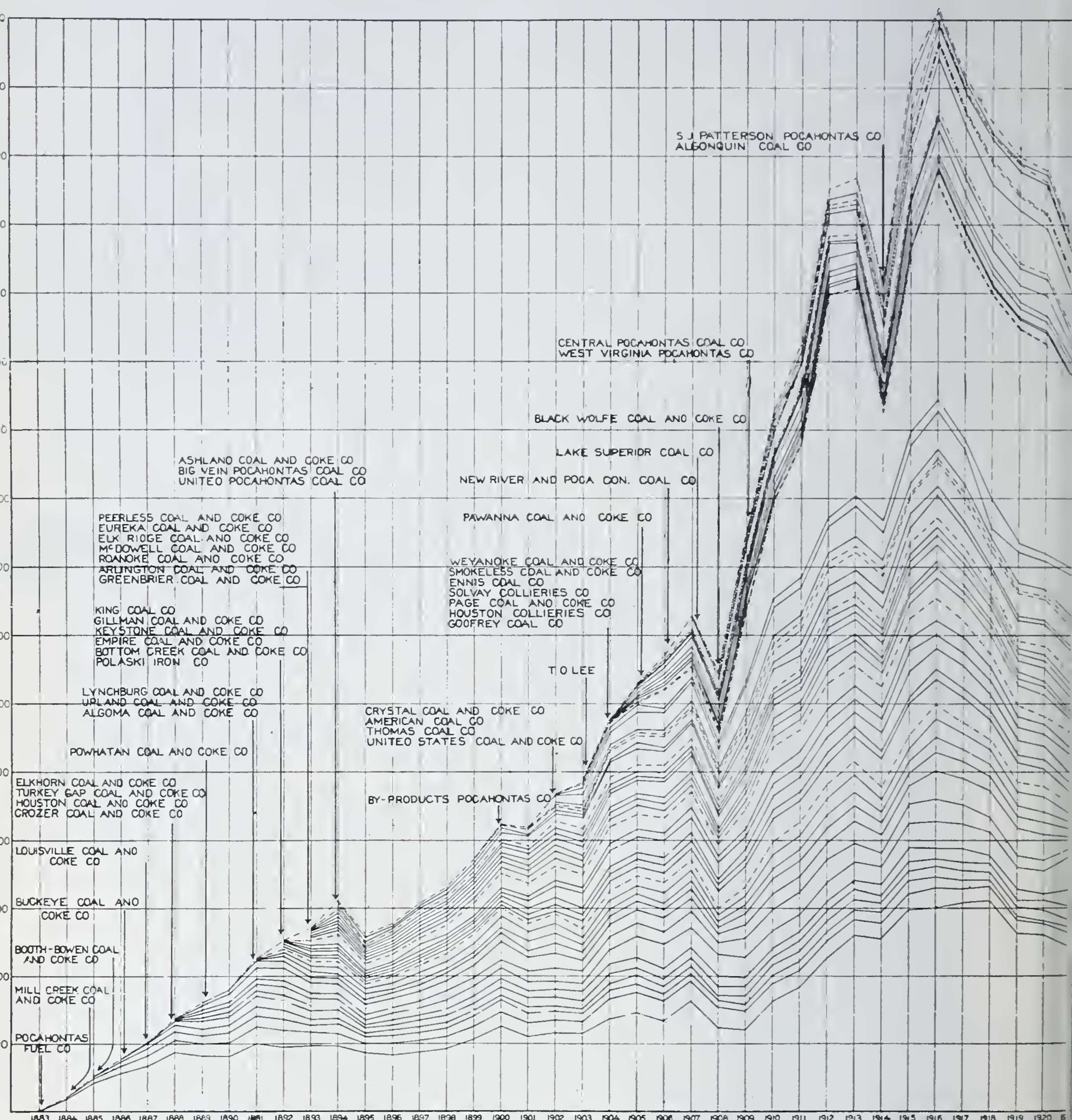

Fig. 4. Coal Production of Pocahontas Broad Top Field.

a slight degree to the recent increase in coal demand, and after lagging behind 1924 for nearly 4 months, have turned upwards slightly. Were it possible to dissect the record for Pennsylvania between union

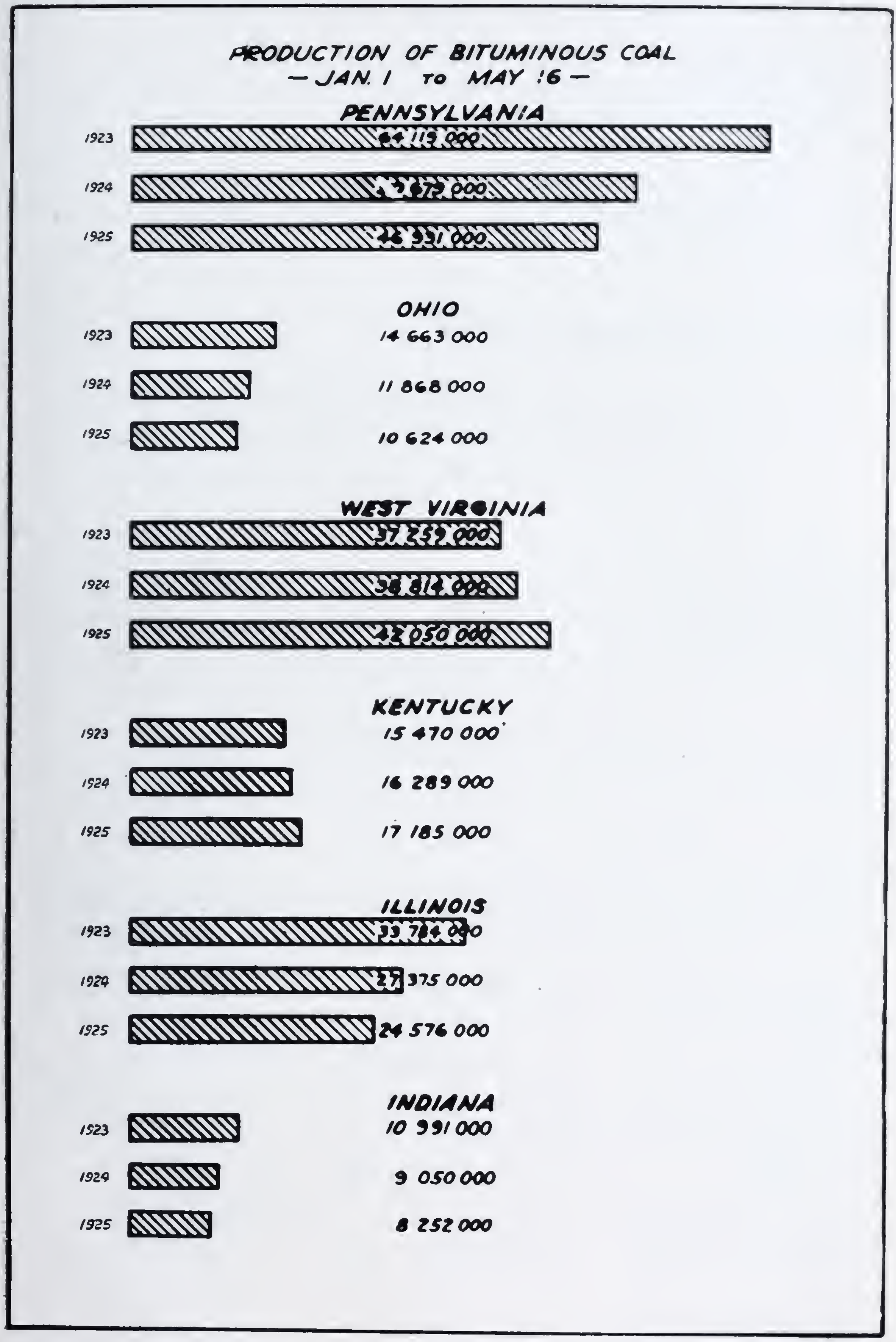

Fig. 5. Gain in Output in Non-Union Areas.

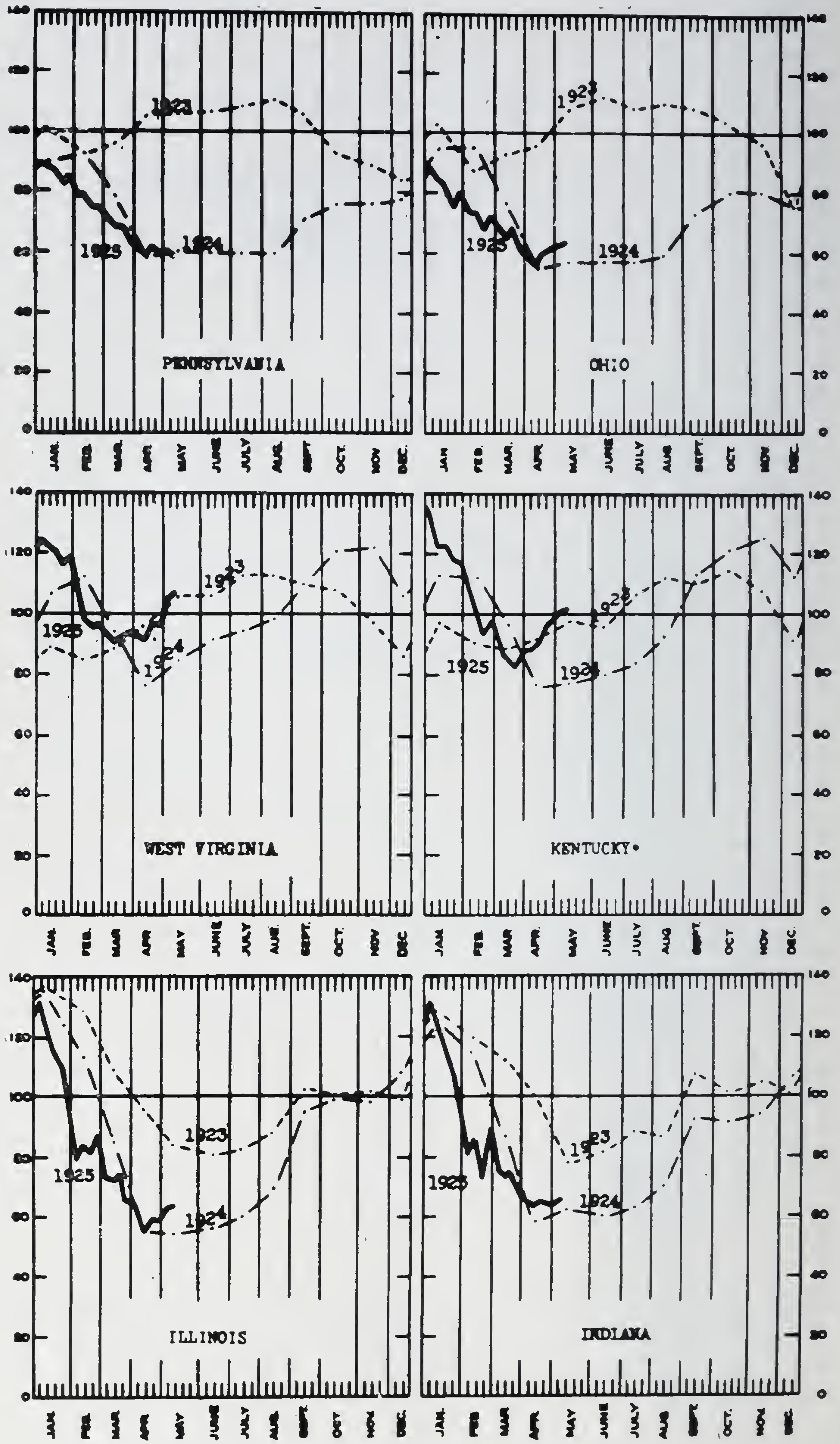

Fig. 6. Index Prices of Bituminous Coal Production.

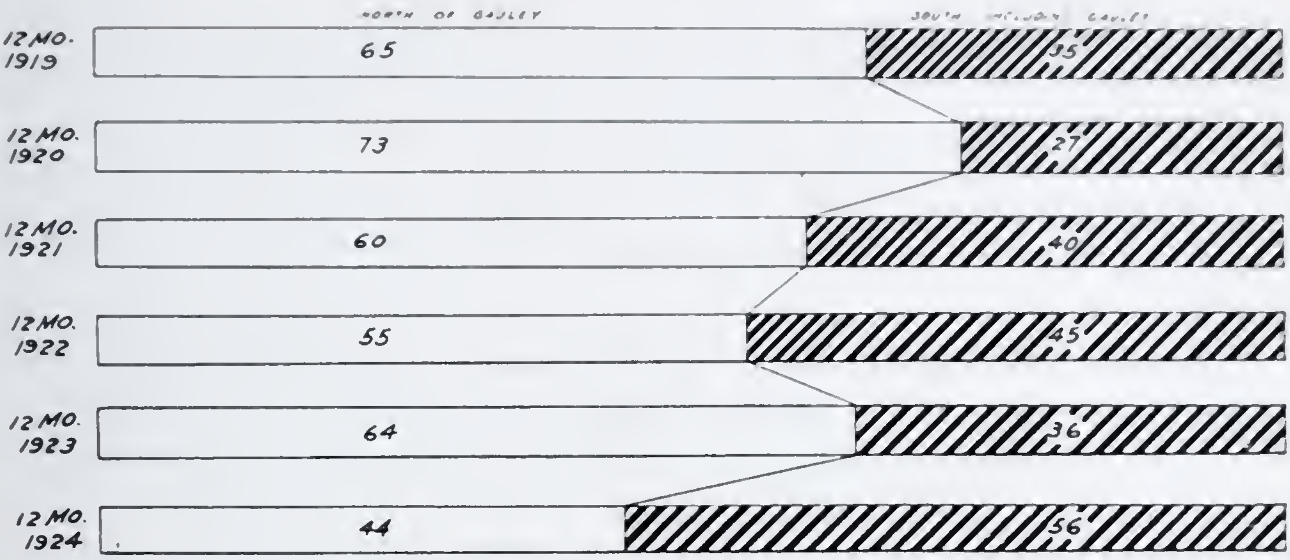

Fig. 7. Lake Shipments of Bituminous Coal.

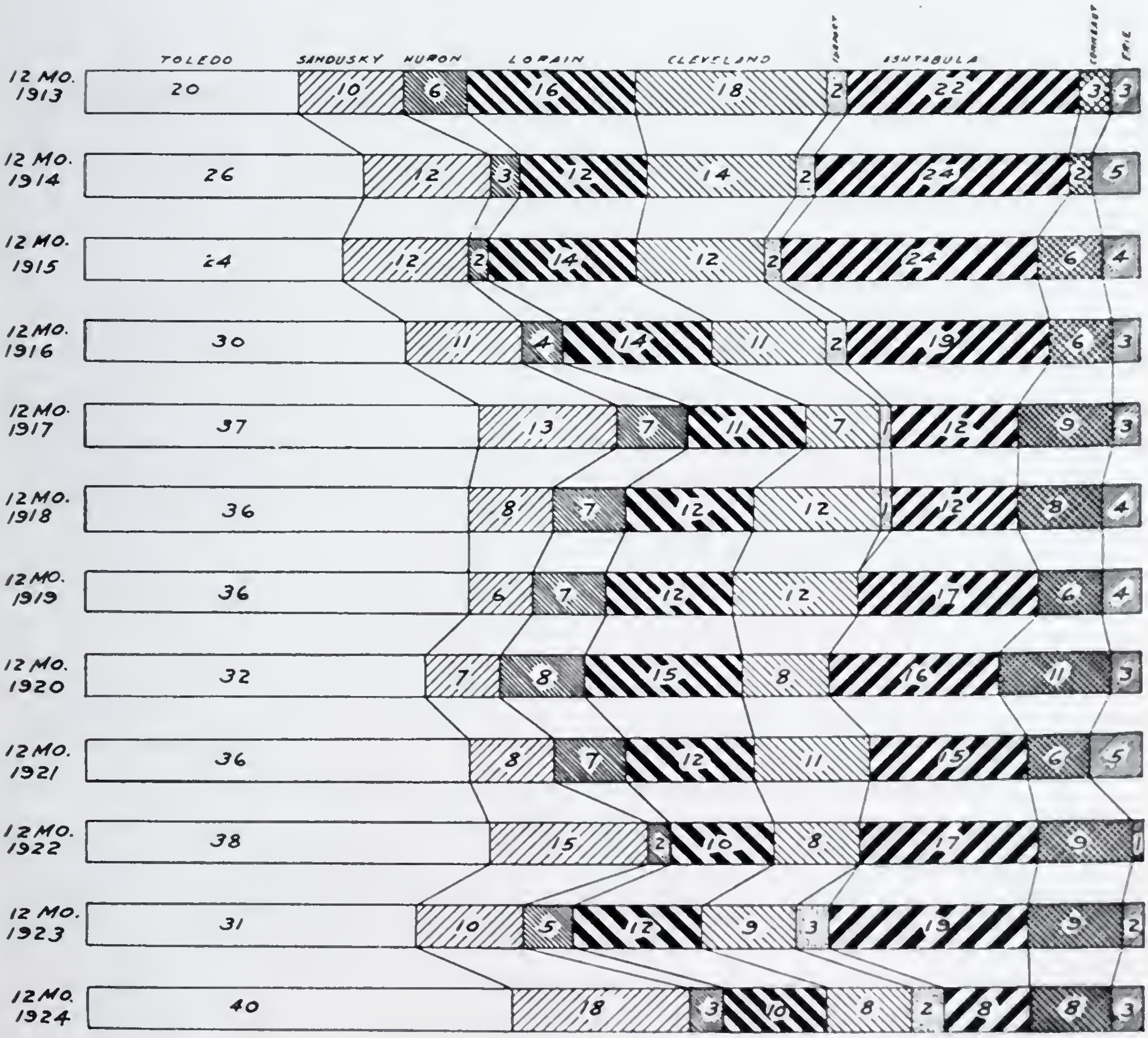

Fig. 8. Shipments of Bituminous Coal to Lake Erie Ports.

and non-union, we would find a steeply downward pitch to the union curve in April and May and an upward turn to the non-union.

West Virginia and Kentucky, however, are climbing over the 1923 peak record. It seems to me that here is a complete answer to the story that coal is not being produced and that price is not taking markets.

Fig. 7 shows percentage of bituminous coal shipments from the Appalachian districts by calendar years, 1919-1924.

Fig. 8 shows percentage of bituminous coal delivered at various Lake Erie ports, 1913-1924.

Fig. 9 shows railroad tonnage of lake cargo coal, 1913-1924.

Fig. 10 shows percentage of bituminous coal shipped to Lake Erie ports from the Pittsburgh district.

Fig. 11 shows shipments to Atlantic ports, 1918-1924.

Fig. 12 shows shipments from Appalachian districts to Central Freight Association territory (between Erie, Pa., and Milwaukee, Wis., on the north and between the Ohio River and St. Louis on the south). These figures do not include coal which railroad companies use for their own fuel, and which bears no freight charges. The records shown are for the first three months of each year from 1920 to 1925, inclusive.

Fig. 13 indicates shipments of bituminous coal from Appalachian districts to Central Freight Association territory. It excludes coal used by originating railroads for their own fuel, and not subject to freight charges. The figures are for the first three months respectively, of the years 1920-1925. In the diagrams, white represents union, and black, non-union production.

Fig. 14 shows labor cost per ton of coal, for several years, in various fields.

Fig. 15 gives index numbers for cost of labor, on the basis of 100 per cent. for the year 1918.

Perhaps the figures for the immediate district will bring the subject nearer home. Commercial operators, members of the Pittsburgh Coal Producers' Association with mines within a few miles of this city, in January, February, March and April of 1923, produced 5,460,000 tons; in the same four months of 1924, 4,383,000 tons; and in the same period of 1925, 3,650,000 tons. The decrease this year below 1923 was 1,810,000 tons or 33 per cent. The drop from

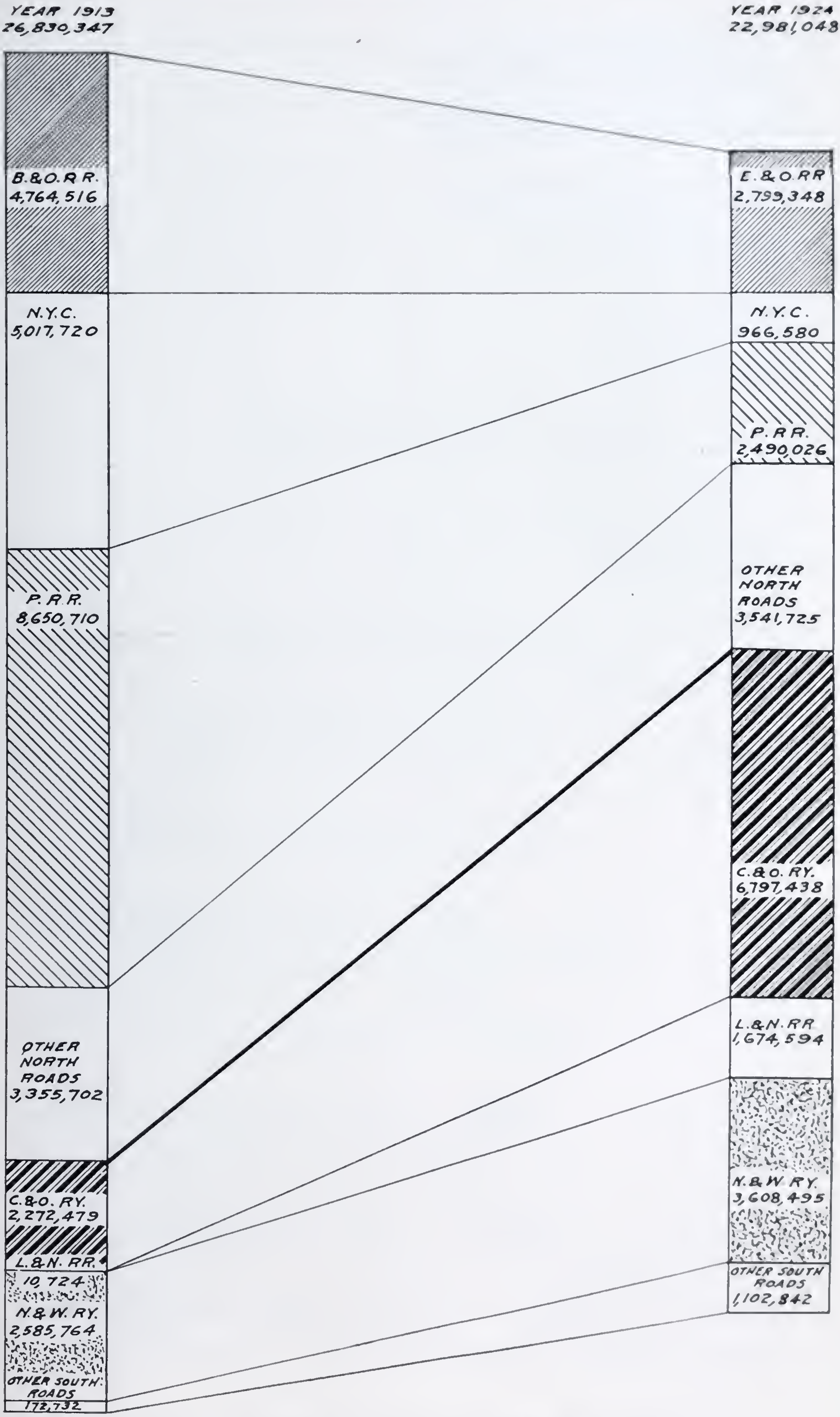

Fig. 9. Railroad Tonnage of Lake Cargo Coal.

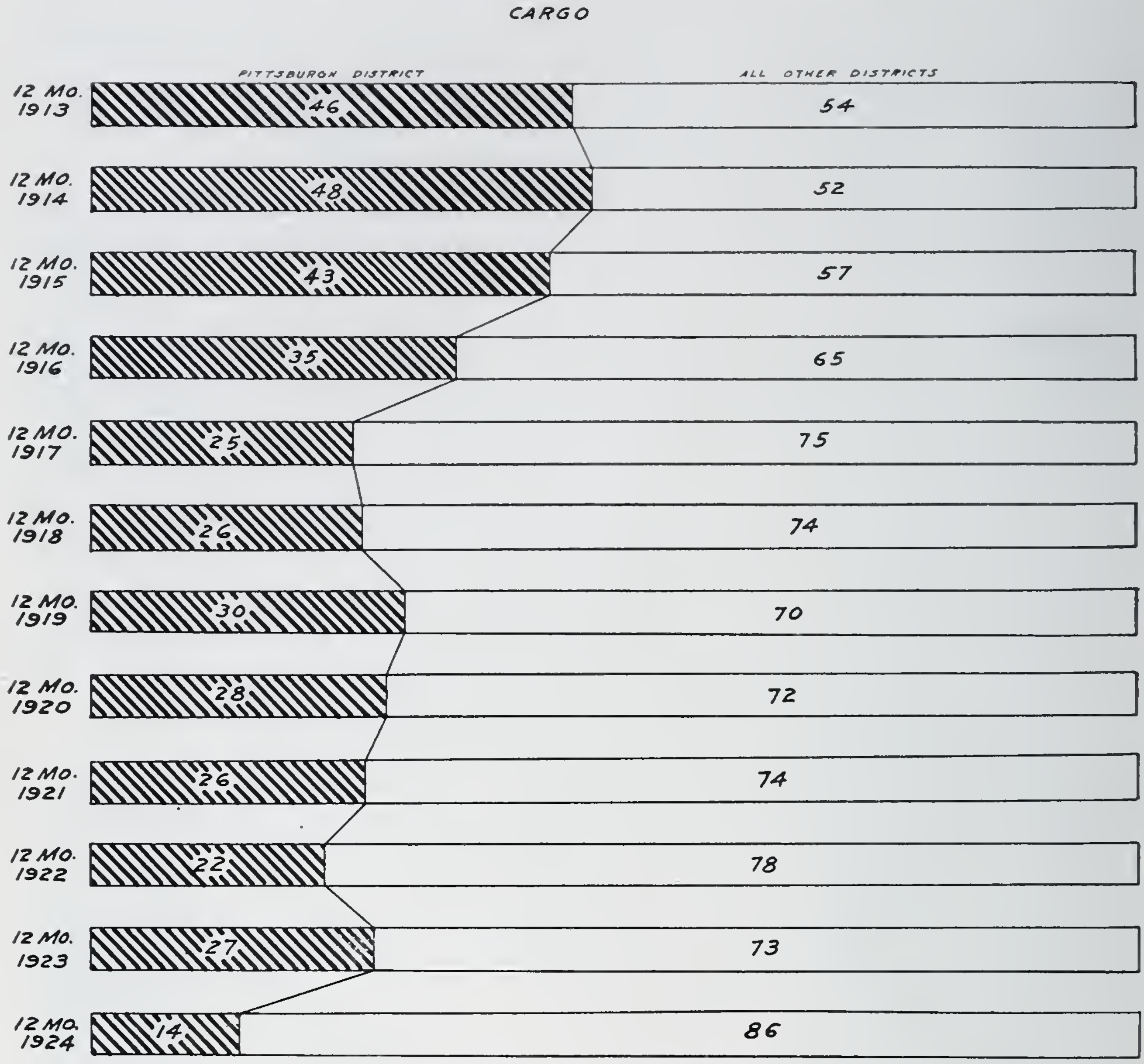

Fig. 10. Shipments of Bituminous Coal to Lake Erie Ports, Showing Percentage from Pittsburgh District.

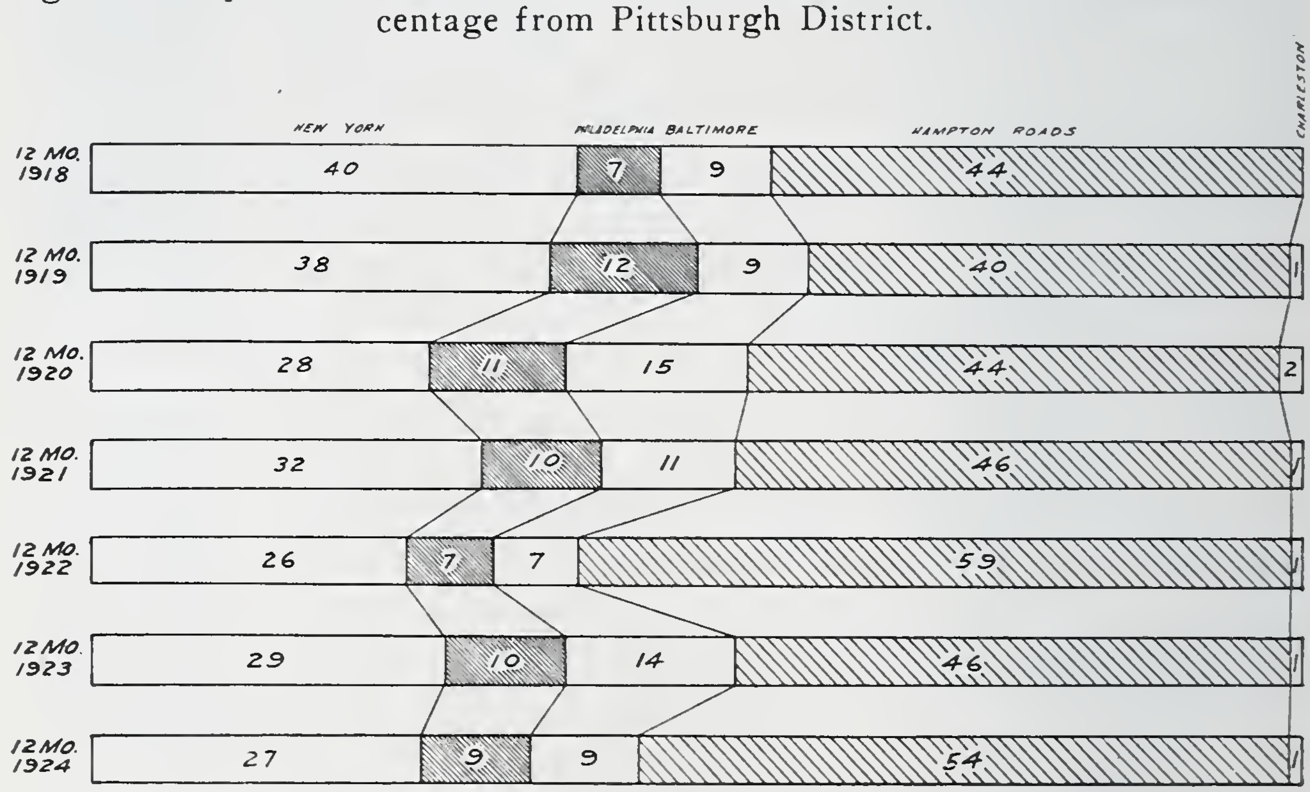

Fig. 11. Shipments of Bituminous Coal to Atlantic Ports.

last year was 733,000 tons or 17 per cent. In May of this year production by these companies was 335,483 tons compared with 878,000 tons in May of 1924 and 1,620,000 tons in May of 1923.

The significant thing about this record is that whereas the production of bituminous coal in the United States as a whole in the first four months of 1925 declined 2.4 per cent. below the same months of 1924, these commercial producers in the Pittsburgh district had a loss in production of 17 per cent.; and in May the production

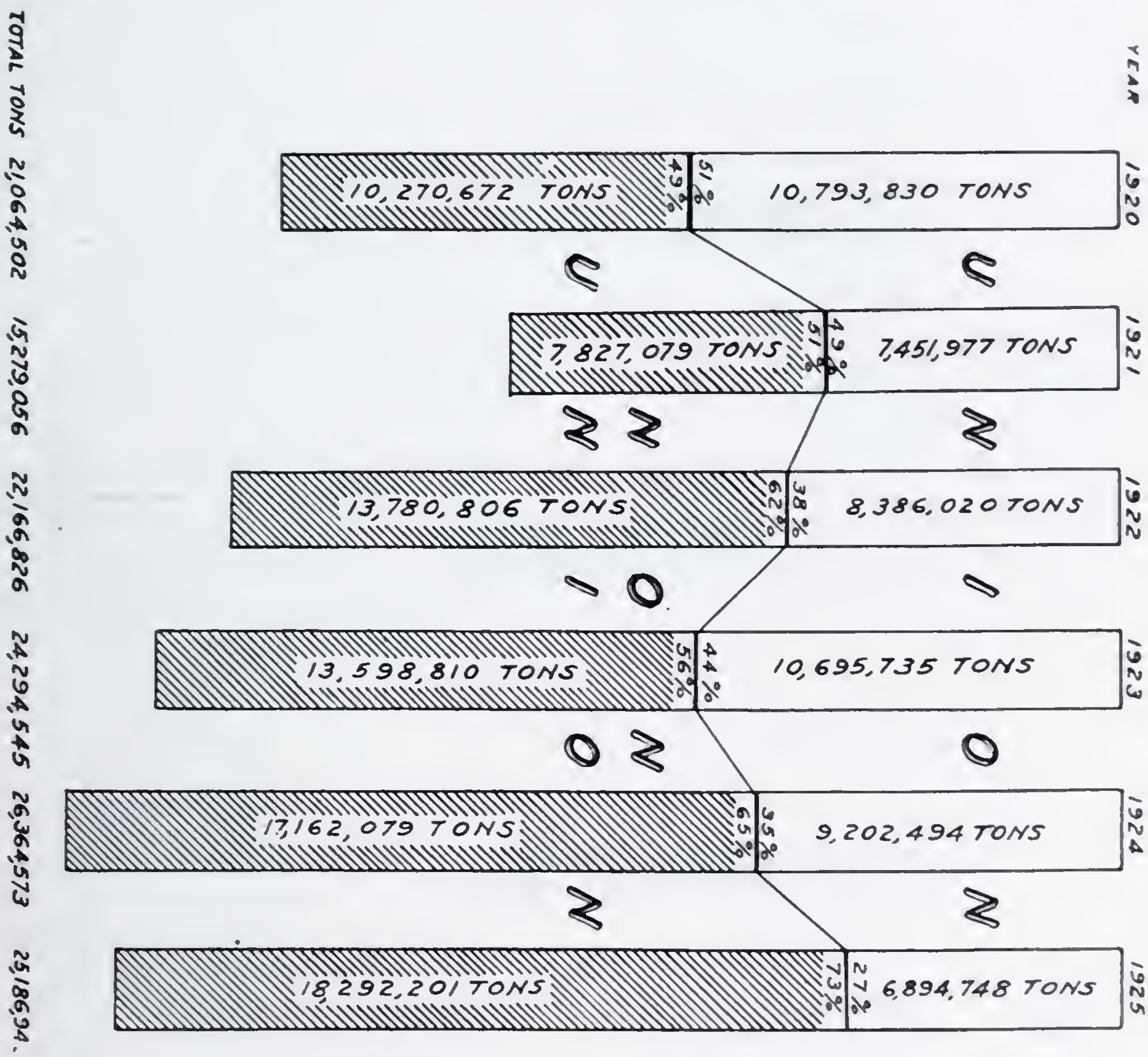

Fig. 12. Bituminous Coal from Appalachian Districts to Central Freight Association Territory.

of bituminous coal in the United States increased more than 4,000,000 tons over May 1924, or 14 per cent.; but, in the Pittsburgh district, commercial production decreased 62 per cent.

Since the first of this year the production of these commercial operations has dropped from 270,000 tons per week to 61,000 tons in the first week of June. A loss in output of 210,000 tons of coal per week in so short a time is only a part of the loss that has been sustained since 1923, but it alone represents a loss in pay-roll of $315,000

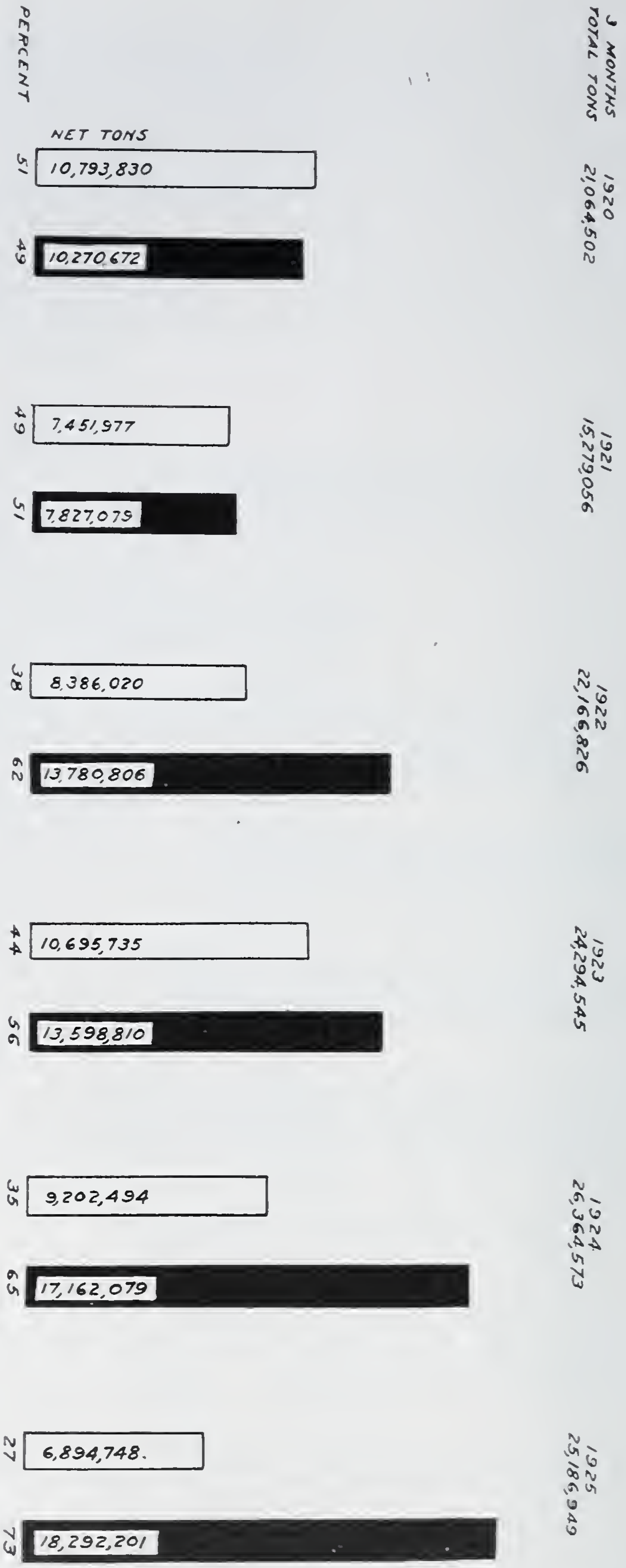

Fig. 13. Bituminous Coal from Appalachian Districts to Central Freight Association Territory, Comparing Union and Non-Union Output.

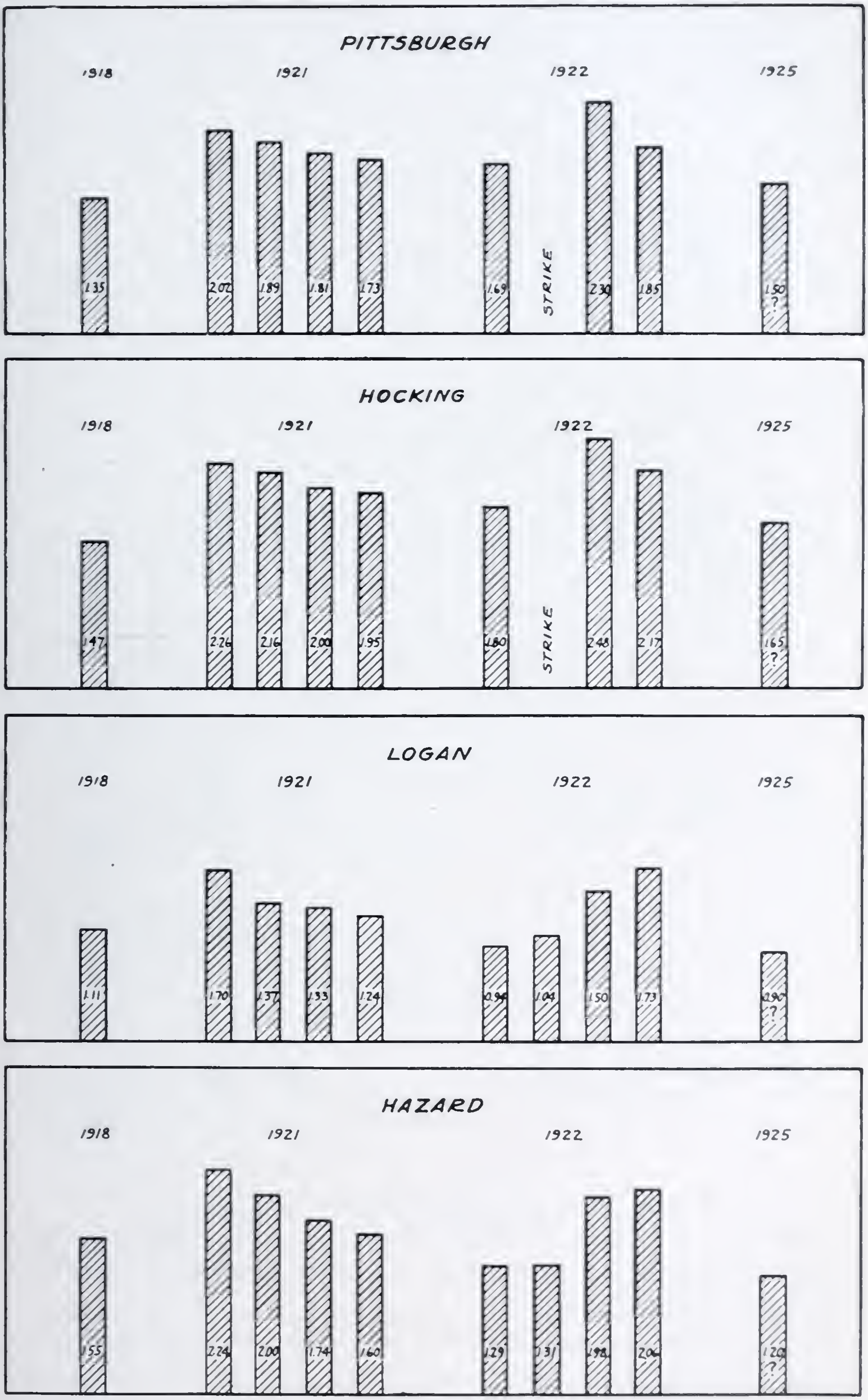

Fig. 14. Cost of Labor per Ton of Coal.

per week. The present depression in the coal industry, taking into consideration the captive as well as commercial operations, at a conservative estimate is costing the Pittsburgh district $800,000 per week in mine pay-roll. Mine supplies not purchased and railroad freights

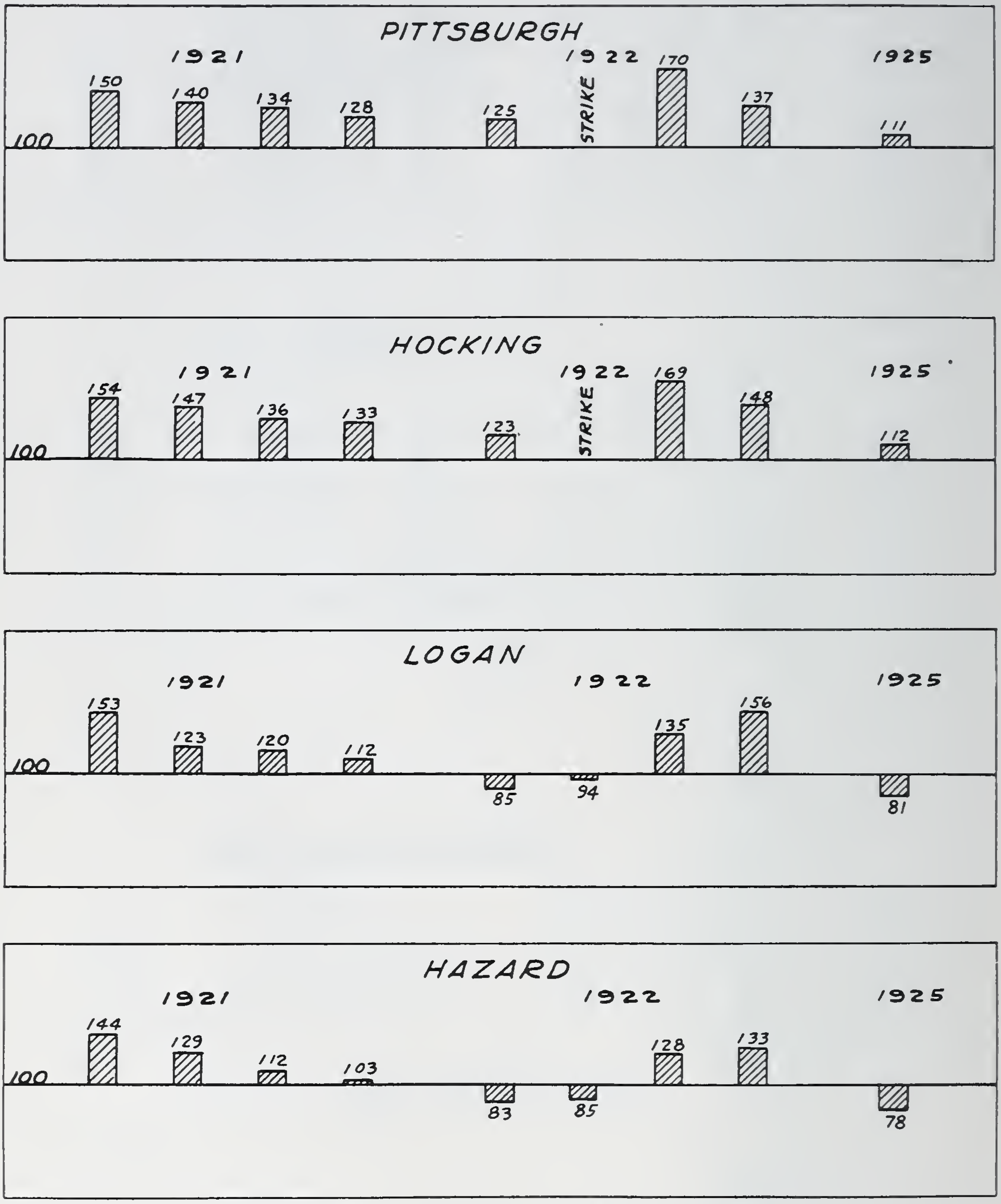

Fig. 15. Index Numbers for Cost of Labor.

not earned represent another large sum that should be contributing to Pittsburgh's prosperity.

To help correct this situation the union operators would like to have the miners agree to a revision of the wage scale. It must be

clear, from what has preceded, that if this district had a lower cost it could sell more coal; with the $5 basic wage of the November 1917 wage scale, this district could secure its share of the going trade, which is not by any means inconsequential.

The stock argument of those who oppose such a revision is that it would be of no avail. It is contended first, as I have stated, that there is no market for coal at any price, and second, that if the miners on the high scale should accept a reduction to the November 1917 level, the operators in the non-union fields would cut their rates still lower and thus nullify any advantage of a cut here.

If that were substantially true it would be a pertinent argument. If the other fields could follow down any reductions in the union fields then it would be a hopeless matter for this field. That is not the case, however. A few there are among the non-union producers who have not cut to the bone, but they are few and far between. Remember that since the present active competition began early in 1924, the non-union operators have been fighting among themselves for the business. This fight has been fast and furious. They have already gone the limit in cutting wages and prices. The competition among themselves has long since resulted in wage scales representing rock-bottom levels. Only by keeping their mines in full operation six days a week, have they been able to hold labor at those low rates.

The non-union wage situation is very sensitive. Recall if you will the history of last winter in the Connellsville region. Independents had cut wages in the summer of 1924 but the United States Steel Corporation had not. In the winter there was a flurry in demand for labor. Up went the wages of the independents to be reduced again in a few months after the flurry was over.

Competition and the survival of the fittest throughout the soft-coal industry can be resumed when the union fields can meet the wage competition of the non-union fields—and not until then; and a cut to the scale of November 1917, will do the trick.

It is argued that combinations among the operators, and the banding together of many smaller operations into a few large corporations, is the solution for the union fields. Adequately financed, such large companies may be able to weather the depression to better advantage than smaller concerns, but they cannot produce coal more cheaply. Those who look to combination as a solution are dreaming

of strength to put up the price. And how can they do that with the disparity in labor costs with the south? How, for instance, can a combination of independents in the Pittsburgh district increase the price of coal? And how can it otherwise make a profit against non-union competition?

Again it is argued that the coal operators should modernize their mining practices; that if the coal producers would use loading machinery they could cut costs without cutting wages. It is hardly necessary to advise this audience of engineers of the progress that is being made in that direction or of the practical difficulties that beset every installation of loading machinery or face conveyors. Time and money will mechanize coal-mining, but don't forget that the non-union fields can be, and are, as active in that direction—in fact, more active than the union fields. The non-union operator has no union to fight when he installs labor-saving machinery.

When a business concern finds itself unable to sell its goods; when the market price drops and a huge inventory remains, that concern either cuts the price and stays in the market, or it goes bankrupt. The union coal industry—operators and miners—are in that condition now. The union theorizes about the situation. The operators are dealing with it in a practical way. The operators tried alone to handle the situation in 1924. They failed. The union refuses to co-operate this year.

DISCUSSION

MR. H. N. EAVENSON, *Chairman*:* There is one point, in the last part of the paper, about changing to mechanical operation and the attitude of the union toward it, that was not stressed as much as the fact warrants. In West Virginia in particular a great many things can be done in the way of changing to mechanical methods that union mines cannot do; and they can go farther and faster in this direction than any union mine can. With them it is simply a question of education, but in the union mines it is not only education but, in addition, it is necessary to overcome the resistance of the union toward any change.

In considering the growth of tonnage of the Pocahontas field, the fact was not brought out that a great deal of this has been due to the use of Pocahontas coal for by-product purposes. Mr. Lesher's figures, as I understand it, do not show the amount of coke that was shipped from that field. Prior to 1909 the percentage of the output of the Pocahontas field that went into coke varied from 30 per cent. to something more than 50 per cent. each year, but since 1909 the tonnage of coke produced has decreased steadily and the percentage of coal has increased, so that now there is only one plant running regularly on coke, while a very large tonnage is shipped to be mixed with high-volatile coal for by-product purposes. This same fact accounts largely for the growth of the Harlan and slightly for the Hazard field, but it has no bearing on the growth of the Logan field, as practically none of that coal is used for by-product purposes.

MR. C. E. LESHER: I do not want to be put in a position of arguing against combinations as being of no value. I wanted to point out that in this district coal is consumed largely by those who own their mines, such as the United States Steel Corporation and other steel companies, two large public service companies, etc. As a matter of fact, in 1923 half of the coal produced in this district was what we describe as captive tonnage. A business combination in an effort to raise the price of coal might be very easily rendered entirely ineffective in that direction by reason of the fact that those who consume this large tonnage already own their own mines. What I had to say had to do with the commercial tonnage that is for sale in the open market, and does not cover the tonnage used in the district.

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SUSPENDED ARCHES FOR BOILER FURNACES*

By Louis Ellman†

When any form of mechanical equipment has been adopted universally by engineers, and has been considered desirable and satisfactory equipment, there must be some advantages gained by its use. In the following I will try to bring out as briefly as possible some of the reasons for the general adoption of suspended arches, and show their application to various conditions.

There was a combination of events which had to do with the general adoption of flat arches in the boiler room:

1. The great cry of fuel economy which has made such headway in the last 15 years and the realization of the great saving which can be effected by proper furnace design. This resulted in the raising and sloping of arches and the tendency to complicate the design of the arch.

2. The general use of mechanical stoking equipment and the tendency toward operating boilers above their normal rated capacity. This also resulted in the raising and sloping of arches to provide proper furnace volume.

3. The use of larger boilers. With wide boilers, the suspended arch is an absolute necessity. As a matter of fact, the general adoption of the use of wide boilers is in part due to the success achieved by the suspended arch. Before suspended arches were considered a success, it was necessary to divide the furnace of a wide boiler and use a center wall and two sprung arches. The center wall occupied space that should have been used for combustion space and was subject to adhesion of clinker and to failure, which resulted in arch failure. The use of a suspended arch makes it possible to build a furnace of any desired width. With the general tendency toward larger boilers and the operation of them at considerably above the normal rated horse-power, the suspended arch becomes a real necessity. Considerable care and thought must be given to the general arrangement of arches from the proper combustion standpoint, depending on the amount of fuel burned, the class of fuel burned, and various other considerations. For these reasons there are various different

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†District Manager, M. H. Detrick Co., Pittsburgh.

shapes of arches which would be impractical to build in the shape of sprung arches.

4. The increase in brick-masons' wages also helped the suspended arch, because less time is required for both the installation and repairing of the suspended arch than is required for a sprung arch.

In the points just brought out we have considered the reasons for the adoption of flat arches from the standpoint of furnace design. From a maintenance standpoint, there are also a number of reasons why the suspended arch has gained such popularity. In a sprung arch each brick is under compression, assuming, of course, that the tie-rods and skewbacks are stable. The difference in temperature between

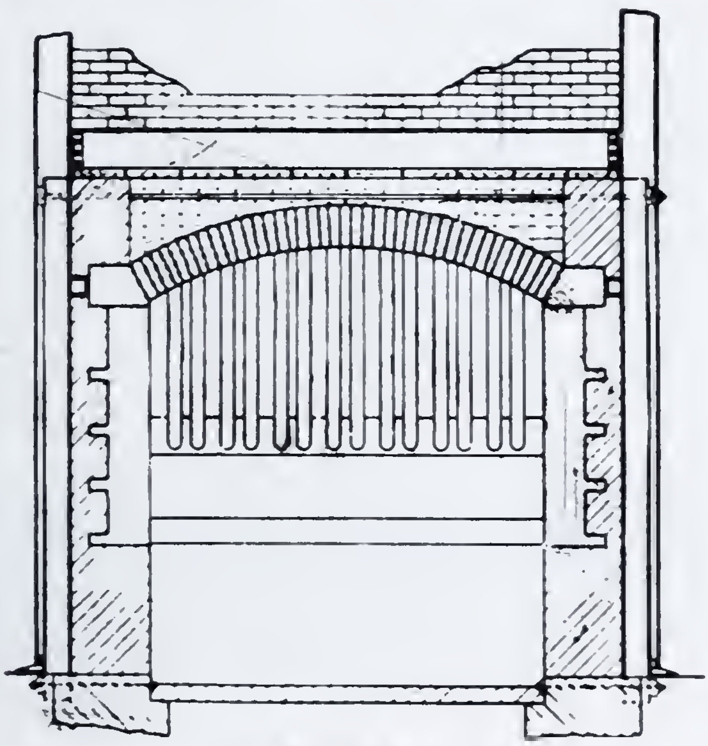

Fig. 1. Boiler Furnace Equipped with Sprung Arch.

the under side of the arch brick and the outside is sometimes as high as 1900 degrees F. The expansion at the inside line of the arch being greater, results in that line becoming longer. This means that the center of the arch rises, allowing gaps between the tops of the bricks. As the arch cools off, the inside line tends to become shorter, allowing the arch to go back to its original place. Practically, however, it never assumes its original position, because, as the arch opens up at the top, soot and dust get into the cracks and gradually work down into the joints, thereby weakening the structure. Continual raising and lowering of the center of the arch due to expansion and contraction will in time weaken the arch until failure occurs. See Fig. 1.

If the tie-rods should stretch, or the skewbacks give, when the arch expands, of course failure will occur even sooner, as with every movement the arch becomes flatter, and after a number of heatings and coolings the arch will collapse. It is a well known fact that the softening point of refractory material is lowered if the brick have to withstand any load; therefore, every brick in a sprung arch has a lower fusion point because of the fact that it is under compression.

The suspended arch consists of structural steel members, cast-iron hangers and specially shaped tile. The steel members are long enough to span the furnace and rest on the side walls. From the steel members, cast-iron hanger bars are suspended which in turn support the specially shaped tile. The arch is made of sufficient width to lap a few inches on each side wall. Between the side wall and the arch an expansion space is provided. With this construction the weight of the arch acts downwardly on the side walls and thereby eliminates the use of skewbacks, buck-stays or tie-rods. In the suspended arch each tile carries its own weight; and therefore the brick are not called upon to withstand any compression, but merely to withstand temperature and the usual wear and tear occurring in furnaces. See Fig. 2.

Fig. 2. Front View of Suspended Arch.

As compared to sprung arches, the repairing of suspended arches is a very simple matter. Suspended arches can be repaired in smaller sections, because the tile are suspended, and in that respect are independent of the adjacent tile. The repairs can thus be confined to limited spaces. Maintenance costs are therefore reduced, because of the fact that less time and labor are required for repairs.

The above advantages of suspended arches, and the fact that they have been used in thousands of installations for a sufficient length of time to prove their value, allow us to reach the conclusion that they are desirable and satisfactory equipment.

For this discussion we will divide the general field for suspended arches as follows:

1. Arches with natural-draft, stoker-fired boilers.
2. Arches with forced-draft, stoker-fired boilers.
3. Arches with powdered-coal-fired boilers.
4. Arches with industrial furnaces.

The development of suspended arches has not been confined entirely to the details of construction. The development from the standpoint of furnace design is very interesting and shows the progress made towards greater furnace efficiency and towards operation of boilers above their normal capacity.

Fig. 3 shows the development in furnace design for forced-draft,

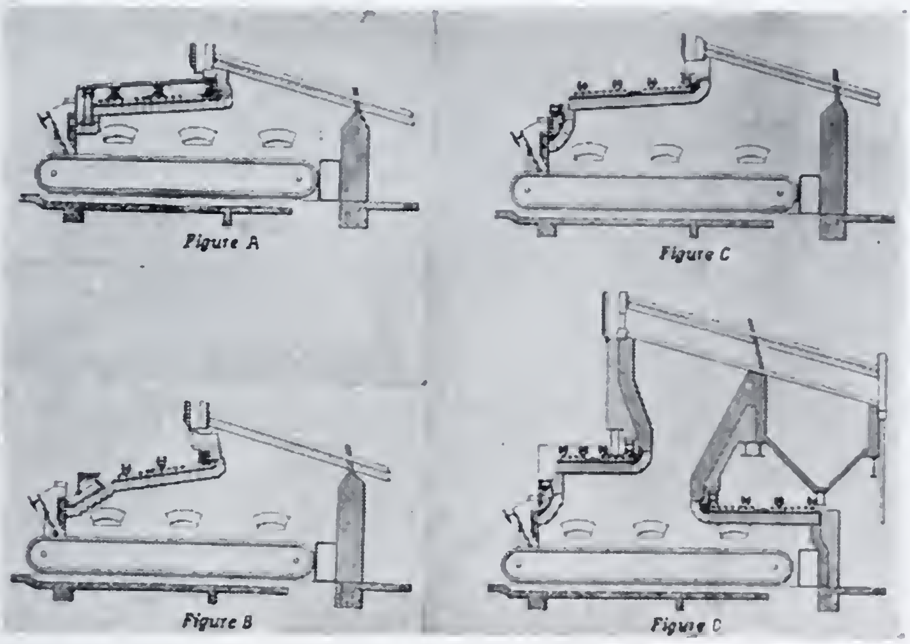

Fig. 3. Furnace Designs for Low-Volatile Fuels, Such as Anthracite and Coke Breeze.

chain-grate stokers and Babcock & Wilcox type boilers burning low-volatile fuels such as anthracite and coke breeze. With certain modifications, these settings can be adapted to the burning of bituminous coal.

In Fig. 3, the sketch marked *A* shows a low-set Babcock & Wilcox boiler with an arch construction and general design of furnace that were used a number of years ago for the burning of either coke breeze or anthracite. The stoker is a Coxe traveling grate. You will note that very little furnace volume is provided. For the burning of low-volatile fuels there is too much uncovered tube surface fairly close to the fire. This will naturally have a cooling action on

the grate. A setting of this kind from a combustion standpoint would probably result in a great amount of combustible in the ash and a low rate of ignition. To burn coke breeze with a setting of this kind would necessitate a very high furnace pressure. The ignition arch did not prove very effective because it was too flat and did not allow sufficient reflected heat rays from the main arch to reach the fuel as it entered the gate. The nose tile on the ignition arch and on the rear end of the main arch were a source of considerable maintenance, inasmuch as two sides of each one of the end tile were exposed to the fire, and these tile would either spall off, or, due to the expansion of the arch, would sometimes be pushed off.

Sketch *B* shows a boiler about the same height, but the arch has been raised and arranged somewhat differently so that undoubtedly a better ignition rate would be obtained. However, the combustible in the ash would hardly be decreased, and there are some criticisms that can be made on the construction of the arch. The main criticisms, as far as arch maintenance is concerned, are the same as those that apply to sketch *A*. The end tile, together with the tile in the step arch, have two sides exposed to the fire, and whenever such a condition exists you can depend upon the tile spalling off or cracking off across the corners. Furthermore, both sketches *A* and *B* show tile of larger size than are shown in any of the following illustrations. We have found by experience that a smaller tile gives better service than a large tile, and, due to the reduction in the size of the tile, we have decreased arch maintenance considerably.

The sketch marked *C* shows the boiler raised a little with a type of arch and general setting that is in use to-day in a great number of installations for both anthracite and coke breeze. Satisfactory results can be obtained with such a setting, provided, of course, proper areas are worked out and proper lengths of arch and stoker are obtained, depending on the fuel to be burned.

Sketch *D* shows one of the most modern and recent installations. You will note that in the other three instances it was possible to increase the ignition rate by the changing of the arch arrangement and the slight raising of the boiler, but it would be very hard to be able to operate even an installation such as *C* at any high ratings without a pressure in the furnace and without considerable ash-pit loss. *D* can be operated when burning either anthracite or coke breeze at high

ratings with no pressure in the furnace and with a very small amount of carbon in the ash. A high rate of ignition is effected, because the highest zone of temperature is between the arches, and this brings the zone of high temperature closer to the gate and the heat reflected from this high-temperature zone increases the rate of ignition. The additional radiation from the face of the rear arch on the fuel as it enters the gate also tends to increase the ignition rate. With the rear arch placed at the proper height, it is possible to carry pressure in the rear compartment and in that way consume practically all of the carbon in the fuel before it goes into the ash-pit, and blow back onto the front part of the stoker the fine particles that have been blown over by the blast in the first and second compartments.

From the standpoint of arch maintenance, an arrangement of this

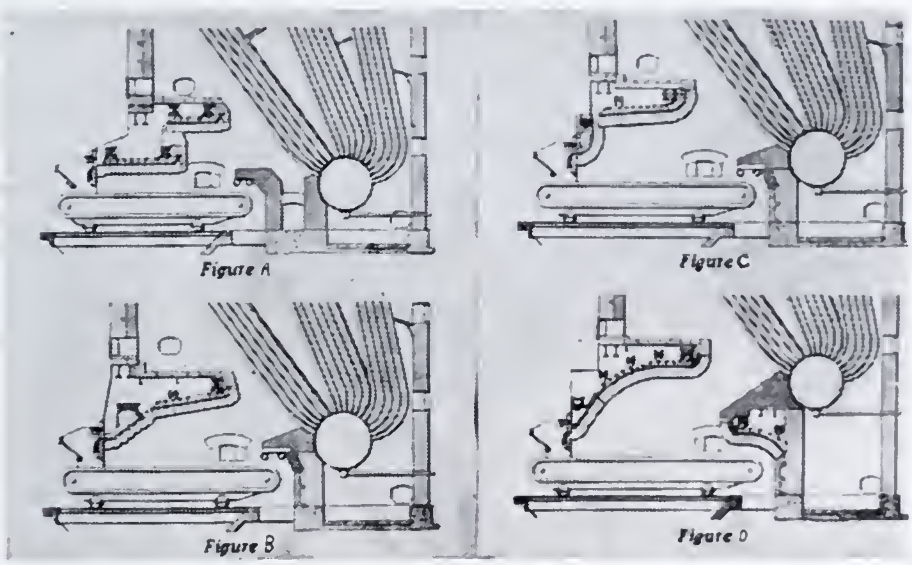

Fig. 4. Furnace Designs for Chain-Grate Stokers Burning Bituminous Coals.

kind is also better than any of the others. By shortening the front arch and keeping the highest zone of temperature between the arches, the maintenance on the front arch is reduced; and, as far as the back arch is concerned, our experience proves that these have stood up very satisfactorily. In the burning of anthracite and coke breeze, especially, care should be given to the proper throat area, or the distance between the front and rear arches. For the burning of anthracite, higher gas velocities are permissible than with the burning of coke breeze. Care should also be taken to make the rear curtain-wall as steep as possible, so as to eliminate as much as possible the tendency of slag to form on the curtain wall.

Fig. 4 shows a Stirling boiler equipped with a natural-draft, chain-grate stoker, burning bituminous coal.

In Fig. 4, the sketch marked *A* shows an old type of setting which did not permit of any great boiler capacities nor very high efficiencies. Ignition was naturally very much delayed. From the standpoint of arch maintenance this can be criticized, particularly as far as the end construction and the use of large tile are concerned. However, a setting of this kind probably was never operated at capacities high enough to give much arch trouble.

In Fig. 4, *B* represents an endeavor to increase the furnace volume and to increase the rate of ignition. Better results would undoubtedly be obtained. You will note that in this case also the boilers are shown set a little higher. With a long continuous arch of this kind, probably greater furnace temperature would be obtained at a point between the arch and the bridge wall, and this in turn would naturally increase the rate of ignition by the heat reflected from this point onto the fuel as it enters the gate. The step arch at the front would allow a considerable number of heat rays to penetrate the fuel as it entered the gate. From a maintenance standpoint, the rear of the arch and the construction of the step arch can be criticized, because very often they would spall or the corners would burn off.

In Fig. 4, sketch *C*, the change that was made was probably more advantageous from the standpoint of arch maintenance than from a combustion standpoint. Probably some gain in combustion would be effected because of the increase in furnace volume near the front of the stoker. It is very probable also that the arch maintenance would be less because of the fact that the arch length was reduced. From a maintenance standpoint, further, the fan ignition arch and fan end arch are far superior to the step arch used in *C*. As stated before, the step arch with the use of large tile, and the fact that each tile had two sides exposed to the fire, was a source of considerable maintenance cost because of spalling. With the fan ignition arch and fan end, a construction is obtained whereby only one side of the tile is exposed to the fire, and, furthermore, the size of the tile is reduced.

Fig. 4, sketch *D*, shows a modern setting of a Stirling boiler equipped with a natural-draft, chain-grate stoker. The boiler, you will note, is set up considerably higher than that shown in Fig. 4, sketch *A*, which makes it possible to design the furnace for fairly high

ratings and good efficiencies. The convex-concave arch that is shown allows the maximum amount of heat rays from the zone of highest temperature to reach the fuel as it enters the gate. Sufficient furnace volume is provided for a high combustion rate. The installation of the rear arch adds two important features. First of all, the heat radiated from the surface of this arch will tend to cut down the amount of combustible in the ash. The other and main item is the fact that it will reduce the tendency toward stratification. In all natural-draft, chain-grate stokers the furnace is operated at a suction ranging anywhere from 0.1 to 0.4 inch. Every ash-pit leaks more or less; therefore you can always depend on a certain amount of air leakage around the bridge wall. There is also considerable air passing through the grate at the rear portion of the stoker where the fuel bed is thinnest. If this free oxygen is allowed to pass into the boiler without mixing, it may develop into secondary combustion in the second pass of the boiler, or gas stratification, which results in lower furnace efficiency. With the rear arch designed as shown, the free oxygen comes into contact with the hydrocarbon gases at the point where the highest temperature is to be found. In other words, the free oxygen is directed into the gases at the point where it is most desirable. A setting of this kind, when burning high-volatile bituminous coals, should give very good capacities and efficiencies.

Fig. 5 shows a front-feed inclined stoker—in this particular case a Roney—together with a Stirling boiler. There are a good many installations of this kind that are using flat arches, and there is very little to be said about this construction or general furnace design. From the standpoint of arch maintenance, it is desirable to slope the arch and also not to make the arch too long. If the arch is set very low and made long, trouble will be encountered from several sources. First of all, arch maintenance; second, clinkering of the ash; and third, burning out of the grate bars.

Fig. 6 shows a V-type stoker with a suspended arch. You will note that in this construction we have a side construction which is part of the stoker side wall that is entirely separate from the arch. The side construction consists of vertical castings that are fastened to steel plates, on which center-slotted tile are strung. The top tile is a key tile and, though this illustration does not show it, there actually is a space between the bottom of the arch and the top of the side tile, so

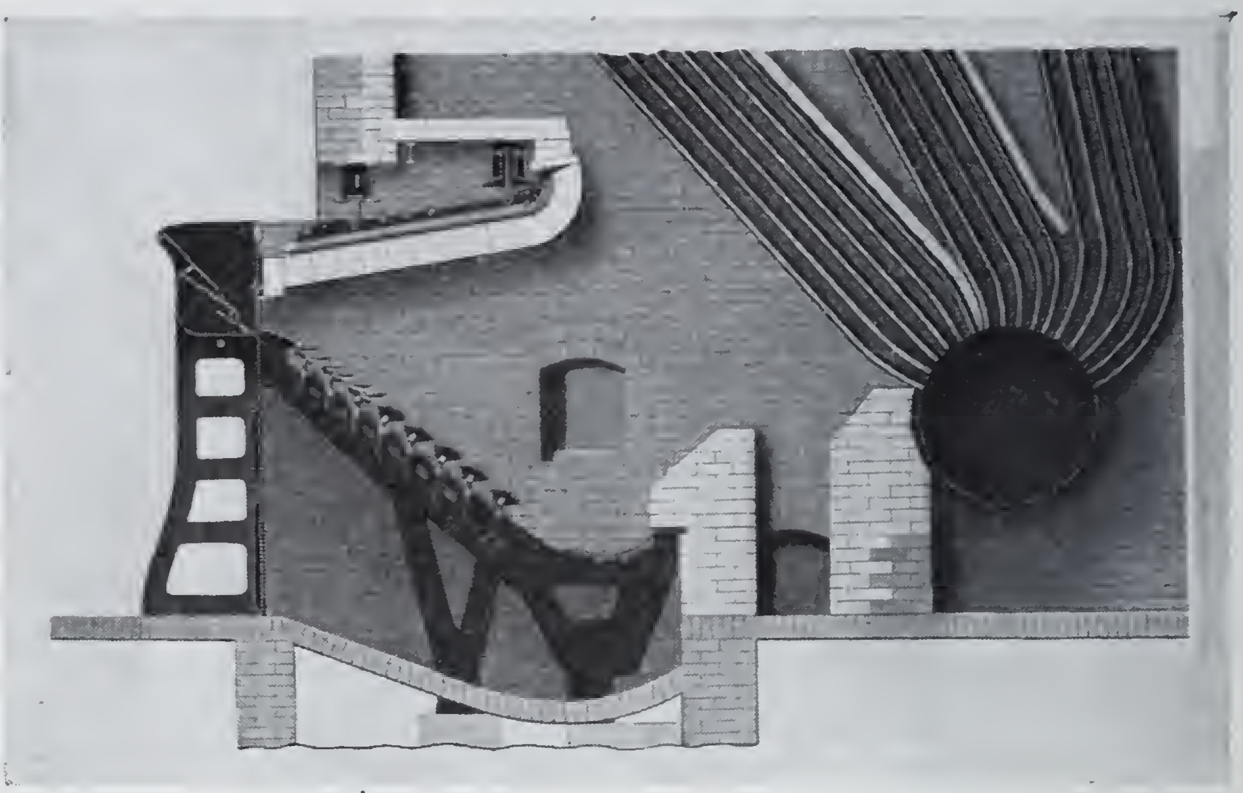

Fig. 5. Suspended Arch Applied to Front-Feed, Inclined Stoker.

that, in order to repair the side construction, it is necessary only to remove the top tile and then slide the others off or break them off without disturbing the arch. The steel supporting members rest on the vertical steel plates, and are entirely separate from the arch side

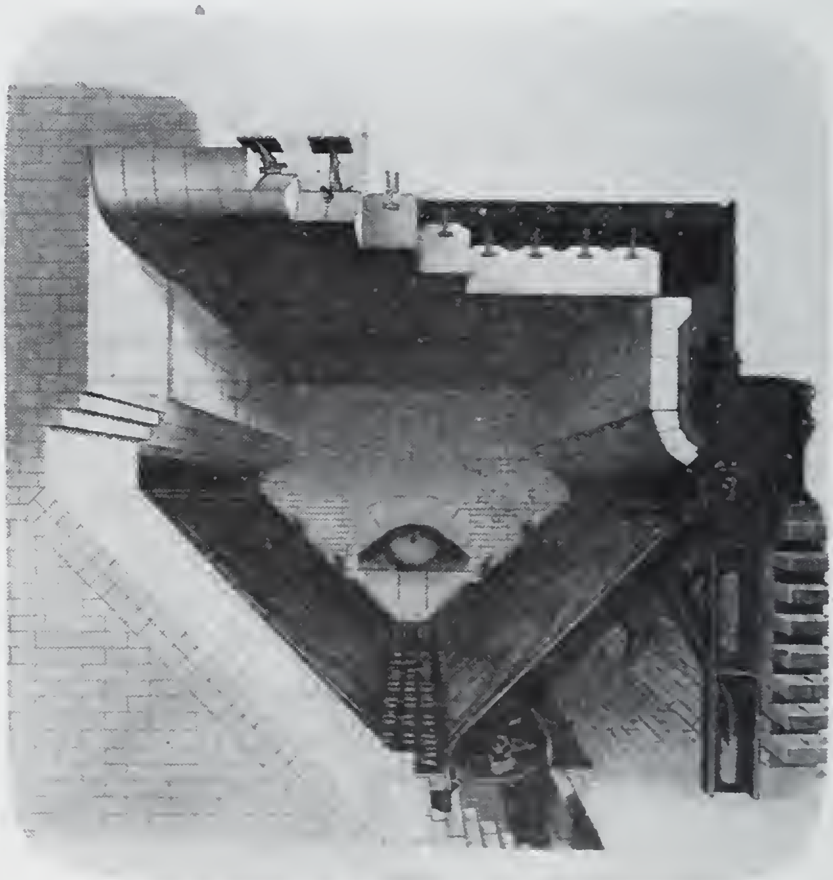

Fig. 6. Suspended Arch Applied to Side-Feed, V-Type, Stoker.

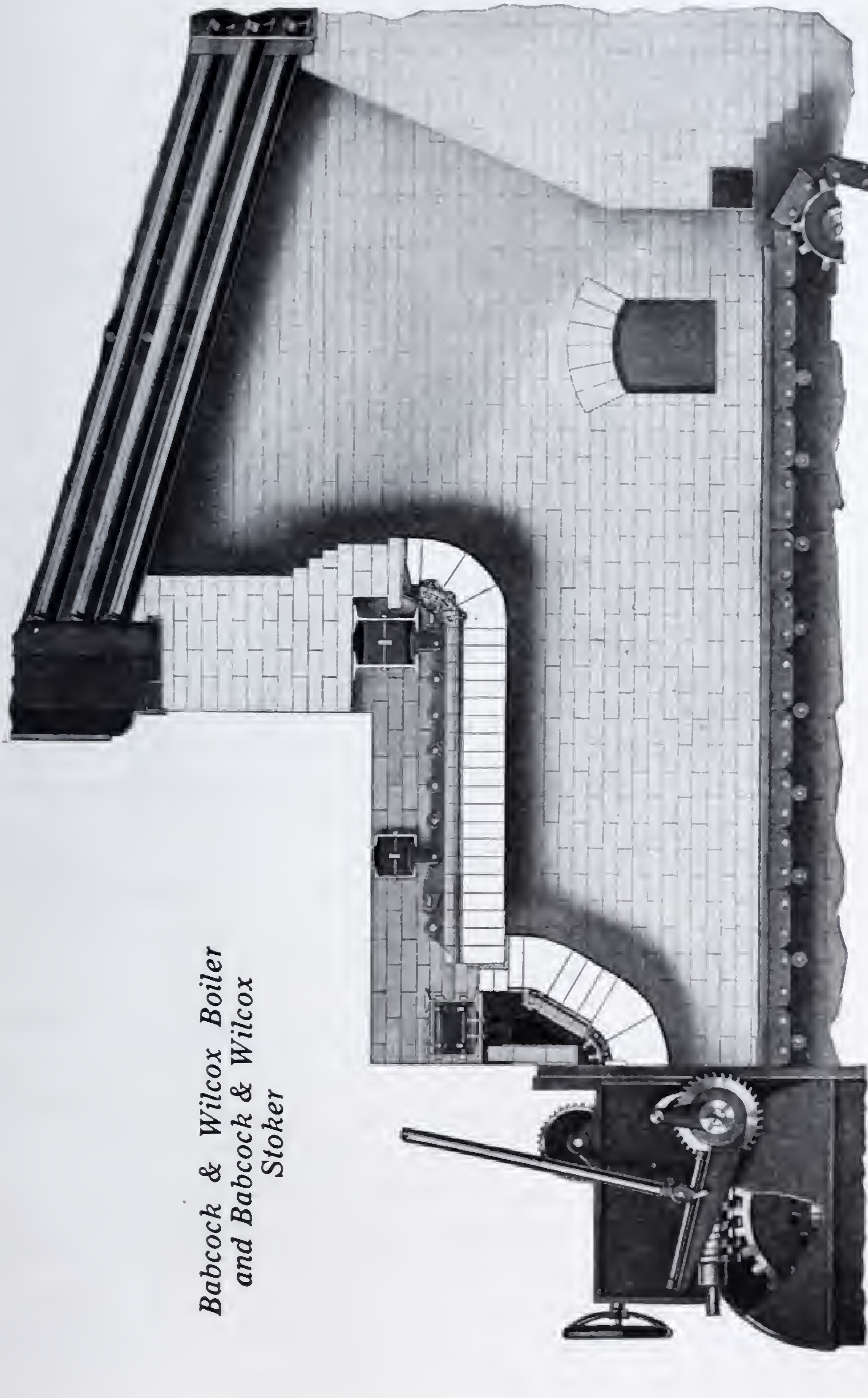

Fig. 7. Suspended Arch Applied to Low-Set Babcock & Wilcox Boiler and Natural-Draft, Chain-Grate Stoker.

construction. In this way, either the arch or the side walls can be repaired without disturbing the other.

Fig. 7 shows a natural-draft, chain-grate stoker. This particular installation is a Babcock & Wilcox stoker and Babcock & Wilcox boiler, with a fan ignition arch and horizontal flat arch which was designed primarily for the burning of bituminous coal. A setting of this kind should give fairly good results for bituminous coal, but probably, if an attempt were made to operate this boiler at high ratings, it would be done at the expense of efficiency, as there is every chance for gas stratification and high ash-pit loss.

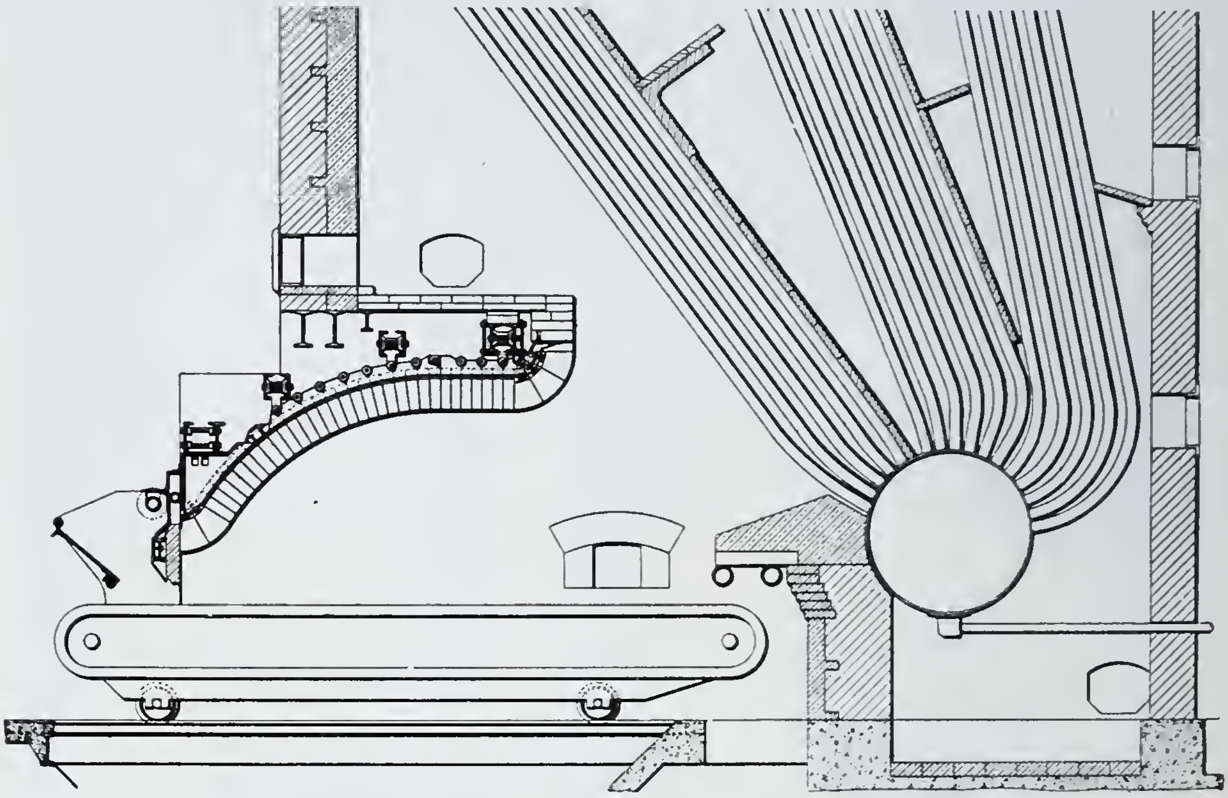

Fig. 8. Improved Type of Suspended Arch Applied to Natural-Draft, Chain-Grate Stoker and Stirling Boiler.

Fig. 8 shows a natural-draft, chain-grate stoker and Stirling boiler with an arch known as the convex-concave arch. You will note that the arch is made long enough so that the tendency for gas stratification is reduced, because of the fact that any air infiltration around the bridge wall will come into contact with the hydrocarbon gases at high temperatures. With this type of arch a high ignition rate is maintained, because maximum heat rays are reflected from the hottest part of the combustion zone.

A chain-grate stoker operates on the principle of progressive combustion. The coal is carried into the furnace, ignited, coked, the

combustible or fixed carbon all burned out, and the ash dumped into the ash-pit. From this method of operation it is apparent that there are three distinct zones of combustion: (1) ignition; (2) coking; (3) burning of fixed carbon. The last part is generally the hottest part of the furnace. It is from this part of the furnace that we should try to reflect as much heat as possible onto the fuel as it enters the gate. In doing this, we increase the ignition rate and thereby increase the capacity. This type of arch, due to its shape, will allow more heat rays reflected from the hottest part of the furnace to the fuel as it

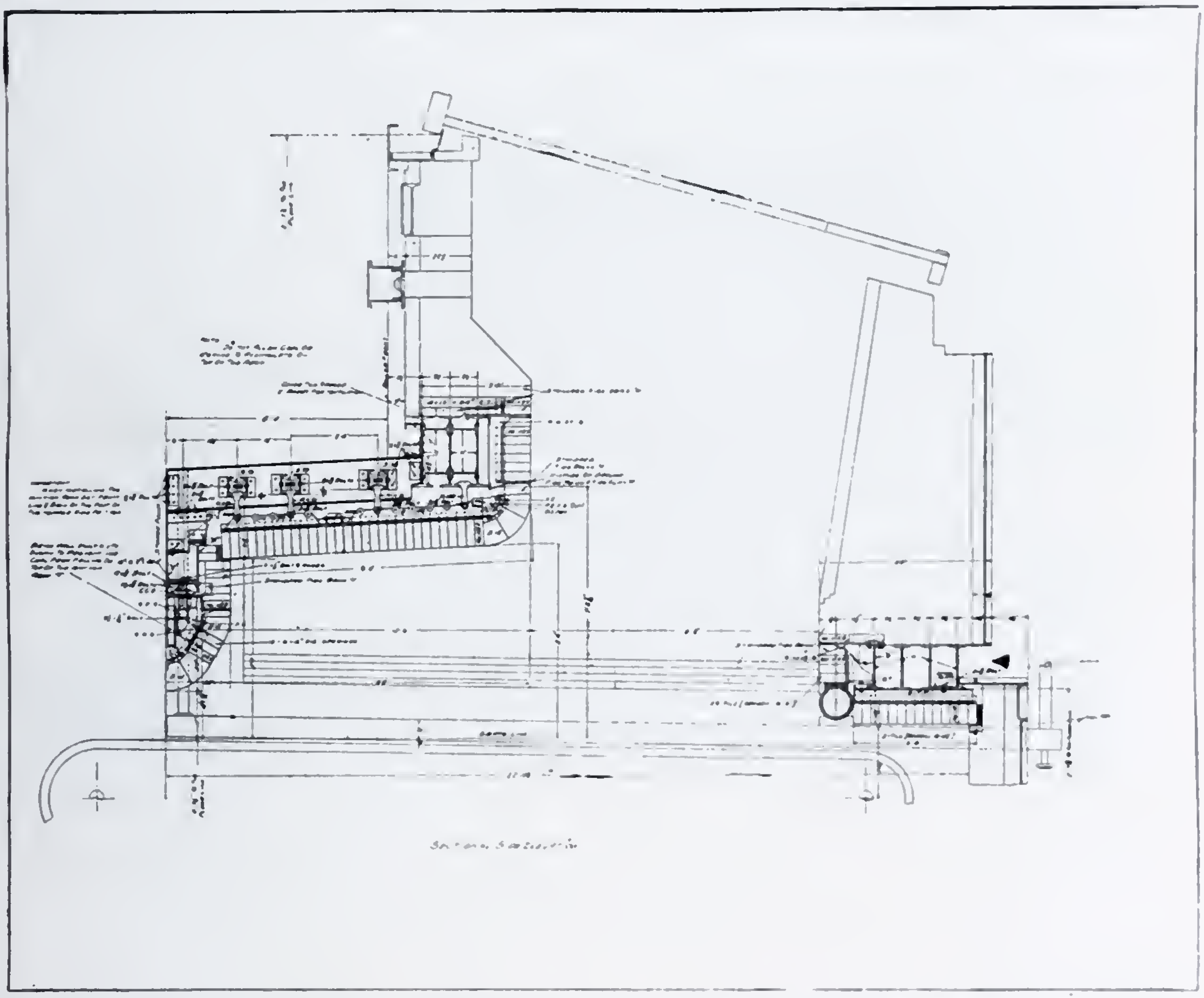

Fig. 9. Suspended Arch Applied to High-Set Babcock & Wilcox Boiler Equipped with Forced-Draft, Traveling-Grate Stoker.

enters the gate. A setting of this kind should give good efficiencies when burning bituminous coal, and fairly high ratings should be obtained. An arch of this kind also stands up very well. You will notice there are no corners to burn or spall off.

Fig. 9 shows a Babcock & Wilcox boiler and Illinois forced-draft, chain-grate stoker, burning Illinois bituminous coal. In the burning of high-volatile fuels, particularly on chain-grate stokers, either forced draft or natural draft, engineers are beginning to realize

that one of the greatest troubles encountered to-day is the stratification of gases. It is well known that when the coal enters the gate and is ignited, the volatile gases are thrown off in the first few feet of the furnace. These gases are rich in hydrocarbons and have a tendency to travel along the arch and up into the boiler. At first glance, therefore, it would seem that the logical thing to do would be to increase the arch length enough so as to sweep them over the portion of the grate where more or less free oxygen enters. From a practical standpoint, however, this is not desirable because it involves high cost of maintenance of arch and side-wall. It is very possible to see that considerable free oxygen will come into the furnace at the back end of the stoker for two reasons. First, because the fuel bed is thinner, and, even if the pressure is kept down in the air compartment, there will be more or less air entering the furnace at this point; and, second, there will always be a certain amount of air entering around the bridge wall and passing out into the boiler tubes as free oxygen. This problem is being watched very carefully and some steps have been made which seem to remedy this situation very nicely.

There is another point to consider, and that is, particularly with high-volatile fuels, a setting of this kind, in spite of its large furnace volume, may smoke. In some plants, provision has been made so that air passes through the arch at several points, and this has eliminated the smoke. At first glance, we might assume that because of the considerable furnace volume in a setting of this kind, mixture of the oxygen and gases ought to take place. However, engineers have found that it is not wise to depend entirely on furnace volume or length of gas travel for proper mixing, unless you have upwards of 30 feet of gas travel.

Fig. 10 shows a Babcock & Wilcox boiler and Coxe forced-draft, traveling-grate stoker. This installation is at the Philo plant of the Ohio Power Company at Philo, Ohio. This is one of the largest and newest stations built, and it has been given considerable publicity because of some of the features and also because of the satisfactory results that have been obtained to date. These boilers are rated at 1400 horse-power. There are two stokers per boiler, with a center wall between. This center wall extends about three feet above the grate line. This station reports a kilowatt-hour on less than 15,000 B.t.u., which, I believe, is a record. The steam pressure at this

plant is 550 pounds at the throttle, and the temperature is 720 degrees. This is a base-load plant with a load-factor of about 86 degrees. Both economizers and air heaters are used. Two units are in operation at the present time. They have four boilers and one 35,000-kilowatt turbine in a unit. One of these boilers is a reheat boiler.

From the bottom of the header to the floor line is approximately 25 feet. You can see that a large furnace volume is obtained. The arch is set high and a small rear arch is used—not so much with the idea of mixing, but more from a construction standpoint. In this installation they have adopted the following means of breaking up the

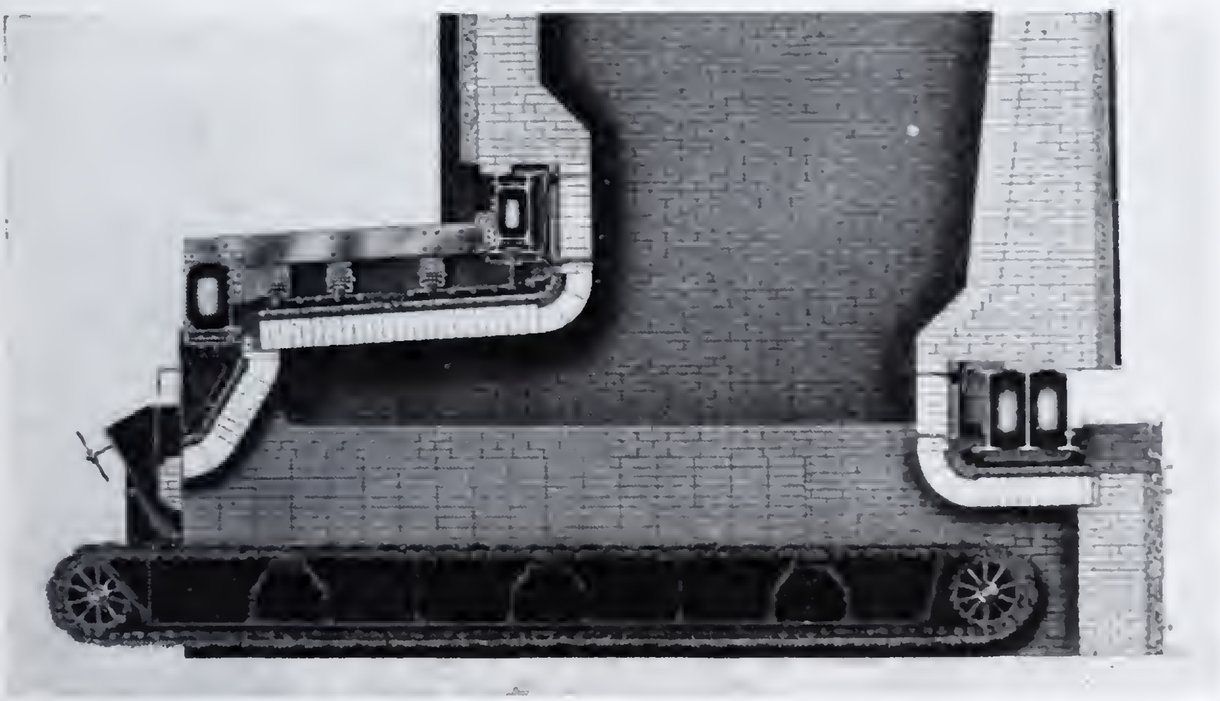

Fig. 10. Suspended Arch Applied to Large Boilers for Stokers Burning Bituminous Coal.

stratification of the gases. The center wall between the stokers consists of a cast-iron box surrounded by tile and brick. The air is taken from the air ducts into this cast-iron box, preheated slightly, and from there is brought into a chamber formed by the two girders which support the ignition arch. From these girders the air is forced through cast-iron nozzles, through the ignition arch, into the furnace. These nozzles are spaced every 10.5 inches apart, and the air-pressure in the chamber formed by the girders supporting the ignition arch will run about one inch water gage. The introduction of air at this point not only breaks up the stratification, but also gives a greater furnace temperature at this point, which, in turn, facilitates ignition. There

is another point that is very important, as far as the introduction of air at this part of the furnace is concerned. Very often, in a setting of this kind, if no air is introduced, a reducing temperature is encountered all along the under side of the arch, due to the lack of oxygen. This naturally reduces the fusion point of the brick and will be detrimental to the arch. With the introduction of the proper amount of oxygen we change this to an oxidizing temperature, or flame, and greater life should be obtained from the arch. You will note the steel construction of the arch for this particular installation. These boilers are 22 feet, 4 inches wide, and the two main girders span the entire width. The cross girders are spaced at thirds of the furnace width. From these girders, smaller beams are suspended, which, in turn, support the castings and tile.

You will note that a curtain-wall construction is used directly above the main arch and directly above the rear arch. Both of these constructions protect the girders supporting both the front and rear walls. The tile used in these curtain-walls are exactly the same pattern as those used in the main portion of the arch, and are strung on vertical castings that are hung from the wall-supporting beams. These castings are spaced 10.5 inches apart, and have a shelf near the bottom and the top. Between this shelf and the top of the curved portion of the arch an expansion joint is provided. The bottom shelf on each of these vertical castings carries the tile up to about the top of the beam, and then the top shelf carries a few tile so as to bring the curtain-wall construction level with the top of the girders. With this construction, it is possible to repair the curtain-wall without in any way affecting the arch, and the end of the arch can be repaired without disturbing the curtain-wall. The construction shown has been adopted by nearly all of the users of large boilers, and has proved very satisfactory. It provides a very simple and satisfactory protection for the front and rear wall girders. You will note that in building a curtain-wall of this kind, it is not possible to build a very thick wall, and, furthermore, there is no chance of binding this wall into the other brickwork. Therefore, if an ordinary 9-inch or 13.5-inch wall were built, there would be every possibility of the wall bulging inwardly and the brick falling in, with the result that the main front and rear wall girders would be left unprotected from the heat of the furnace.

Fig. 11 shows a Babcock & Wilcox boiler and Westinghouse

underfeed stoker. You will note that the arch is inclined steeply, and really forms part of the front wall. A construction of this kind is very often required where underfeed stokers are installed with existing boilers and it would cost too much to change the under-floor construction. If a long stoker is used, it projects out in front of the boiler, necessitating some construction of this nature. There are a good many suspended arches in use in connection with just such settings, and they have given very good results as regards maintenance.

Fig. 12 shows a Connelly boiler and Riley stoker. In this case it was found desirable to maintain as much distance as possible from

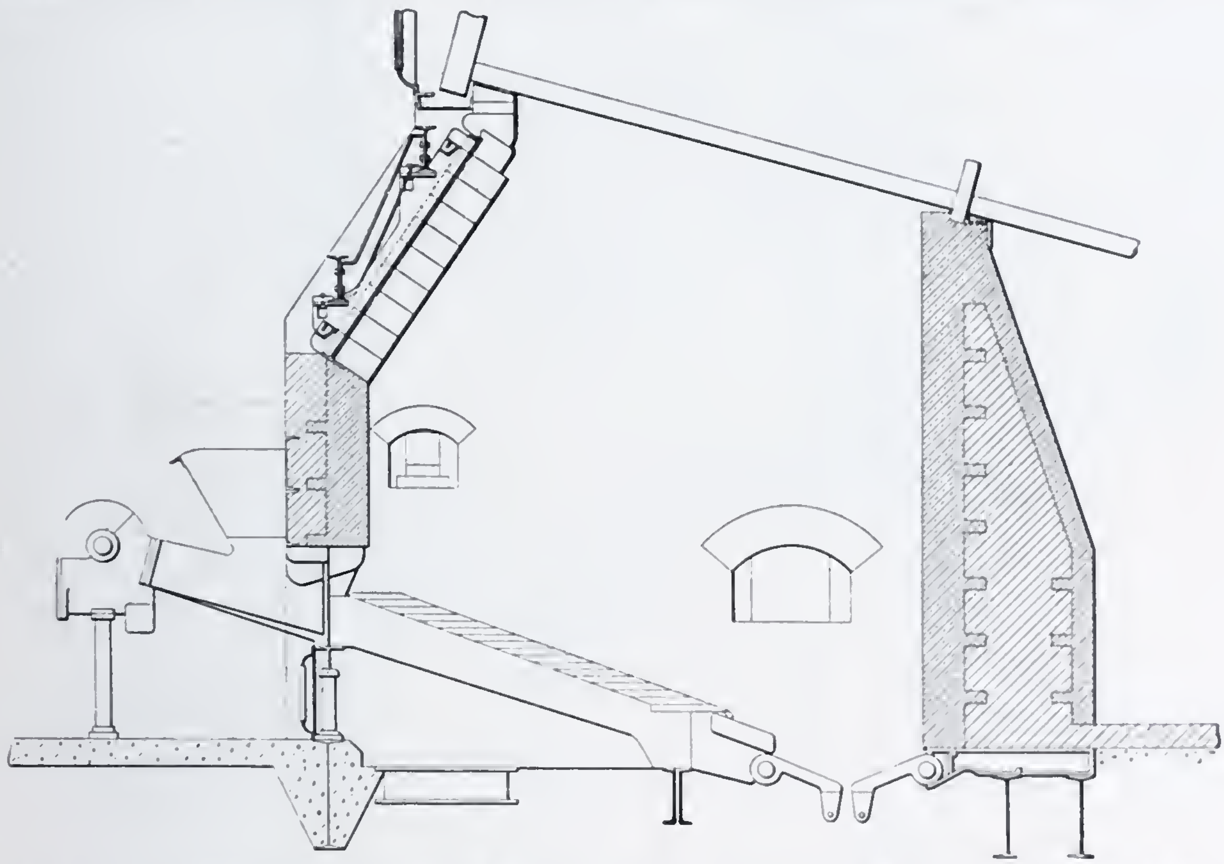

Fig. 11. Suspended Arch Used as Inclined Front Wall for Babcock & Wilcox Boiler Equipped with Underfeed Stoker.

the front of the boiler to the boiler-room wall, and thus, for the grate surface required, a long stoker had to be used, which necessitated some sort of overhang between the bridge wall and the lower drum of the boiler. This construction makes a very substantial and desirable one. You will note that the castings are supported from the main girder, and this girder is tied into vertical columns on the outside of the setting and then is braced back to the horizontal members under the rear wall. Port openings should be allowed for ventilation around this rear girder, and provision should be made for removing any soot or fine particles of coal which will always get around these beams due to

the movement of the boiler drum, which opens up the space between the boiler drum and the brickwork and gradually works the soot down into the space around the girder. Various means can be provided for cleaning out that space, and there is a number of suspended arches in connection with such settings that are giving very satisfactory results.

Fig. 13 shows a Type "E" stoker and Wickes vertical boiler. In a setting of this kind, the proper thing to do is to get as much furnace volume as possible and to shape the arch so that the gases are well directed toward the boiler tubes, and at the same time try to cut down

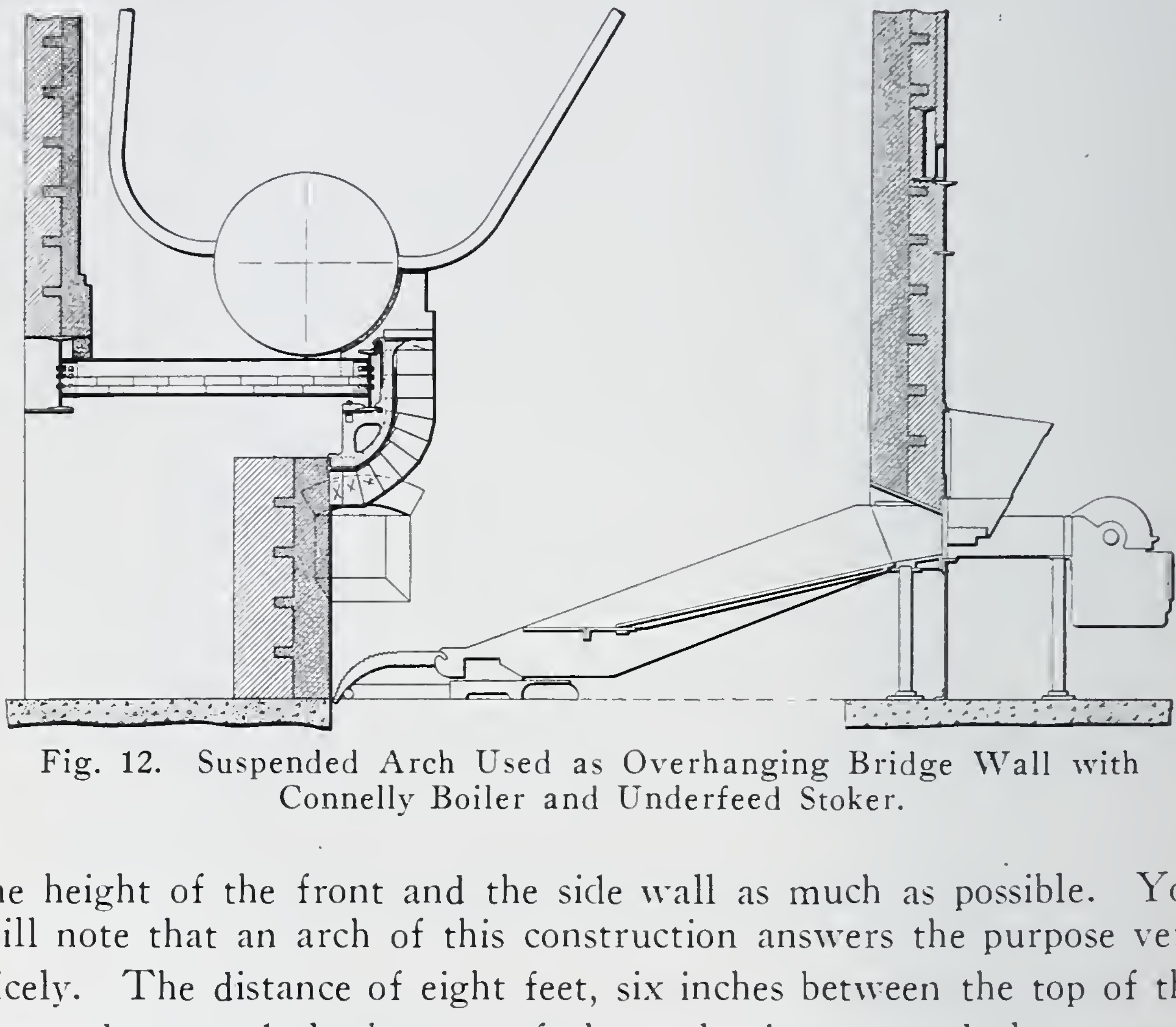

Fig. 12. Suspended Arch Used as Overhanging Bridge Wall with Connelly Boiler and Underfeed Stoker.

the height of the front and the side wall as much as possible. You will note that an arch of this construction answers the purpose very nicely. The distance of eight feet, six inches between the top of the lower drum and the bottom of the arch gives a good throat area. Also, a sufficient area of tube surface is exposed to keep down the velocity of the gases and the amount of slag on the front bank of tubes. If this were a chain-grate stoker, a setting of this kind could be objected to, on the grounds of stratification. In the case of underfeed stokers, however, stratification is one of the factors that does not have to be considered. Because of the very nature of an underfeed stoker, the green coal is forced through a bed of incandescent fuel, so that the volatile matter is being distilled in a zone of very high tempera-

ture and is being intimately mixed with the air from the wind boxes. A setting of this kind should give very good results, up to the limits of the practical operation of the boiler.

Fig. 14 shows a 3000-horse-power double Stirling boiler equipped with "Lopulco" pulverized-fuel-burning equipment. This installation is at the plant of the Cleveland Electric Illuminating Company, in

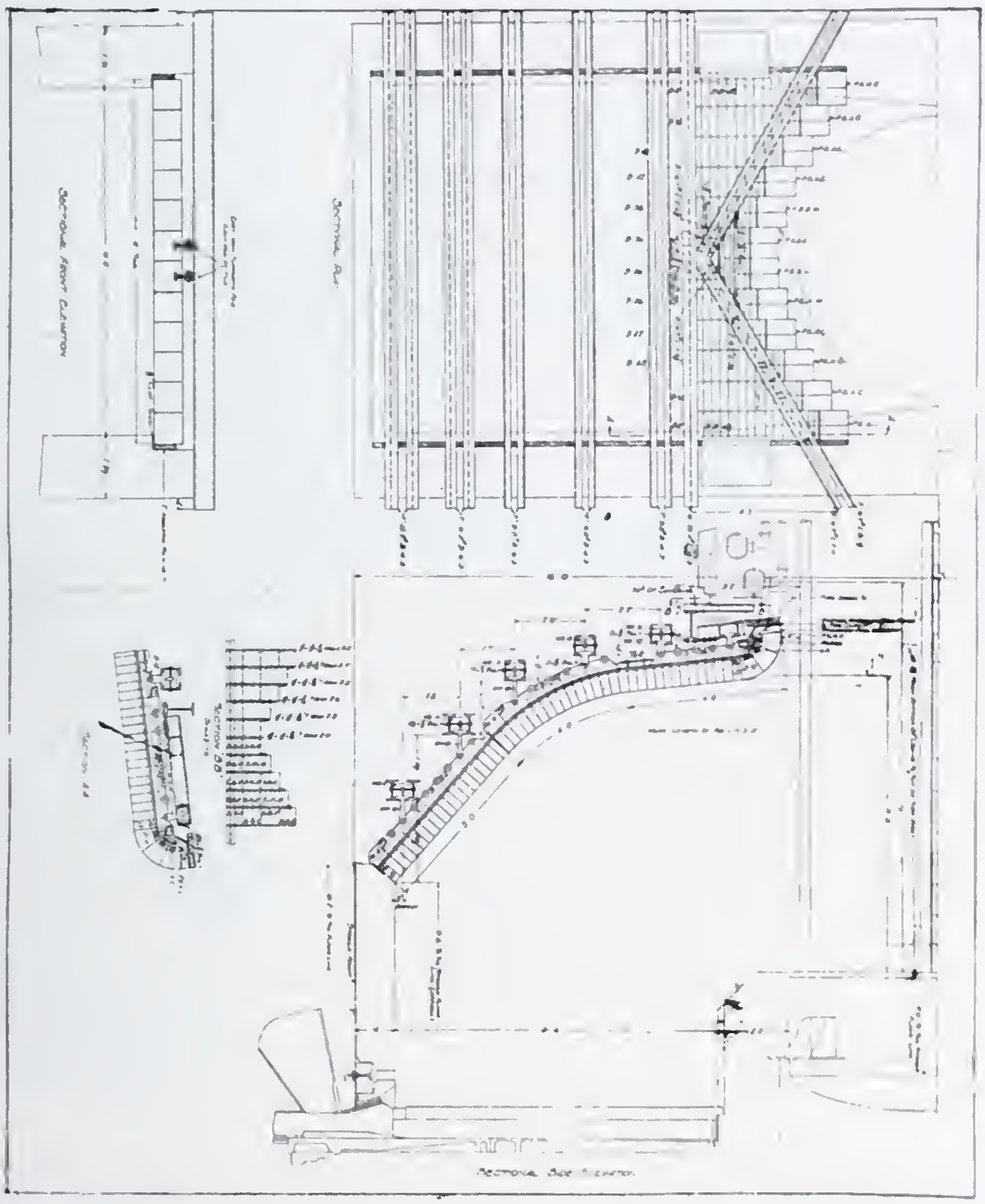

Fig. 13. Improved Type of Suspended Arch Applied to Wickes Boiler Equipped with Underfeed Stoker.

Cleveland, where four such boilers are installed. The furnace width is about 25 feet, and the distance from the water screen to the under side of the arch is about 18 feet. This installation is one of the largest and most recent pulverized-fuel installations in the country, and has a ratio of 1.16 square feet of boiler heating surface to one cubic foot of furnace volume. In other words, you will note there is almost one

cubic foot of furnace volume for every square foot of heating surface, which means approximately 10 cubic feet of furnace volume per rated boiler horse-power. Very satisfactory results have been obtained from this installation. While in certain powdered-fuel installations, arches do not get any severe service from heat radiation, in this particular installation the two arches face each other, and the rear ends of the arches have to withstand pretty hard service. On all such installations careful attention should be given to the detailing of the arch around the burners, and it should be insisted upon that the tile around the

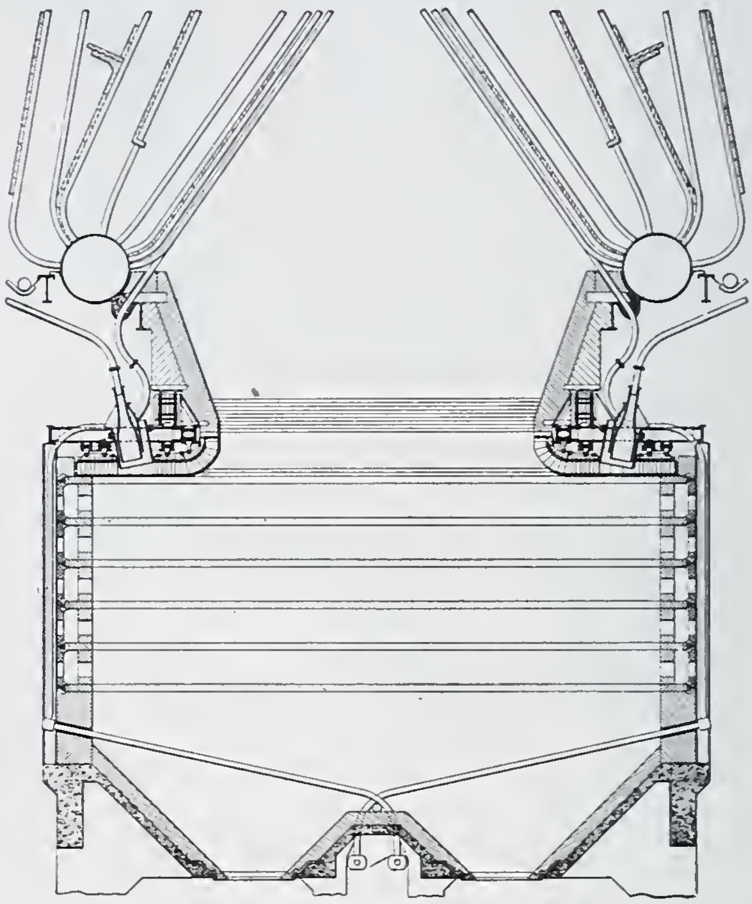

Fig. 14. Suspended Arches in Connection with Pulverized-Fuel-Fired Double Stirling Boilers.

burners be removable and a design worked out so that a simple and satisfactory construction, as far as the details are concerned, be provided.

Fig. 15 shows an installation of a pulverized-fuel-fired Edgemoor boiler in connection with "Lopulco" equipment of the Milwaukee Electric Railway & Light Company. Considerable has been written about this installation, as this is one of the oldest and largest installations with pulverized-fuel equipment in central-station plants. In this installation they have a radiant superheater as part of the rear wall. The furnace volume is about the ratio of 1.86 square feet of boiler

heating surface to one cubic foot of furnace volume. From this you will note that the cubical content of the furnace is not as much as that of the Cleveland Electric Illuminating Company. This plant operates at very high thermal efficiency, the average operating record being 16,000 B.t.u. per kilowatt-hour. This also is a base-load plant with a load-factor of 67 per cent. The boilers are equipped with economizers, but no air heaters. In both installations shown, hollow walls are used, taking the air into the side-walls either by doors located in the side or through the rear wall, and passing along the side-

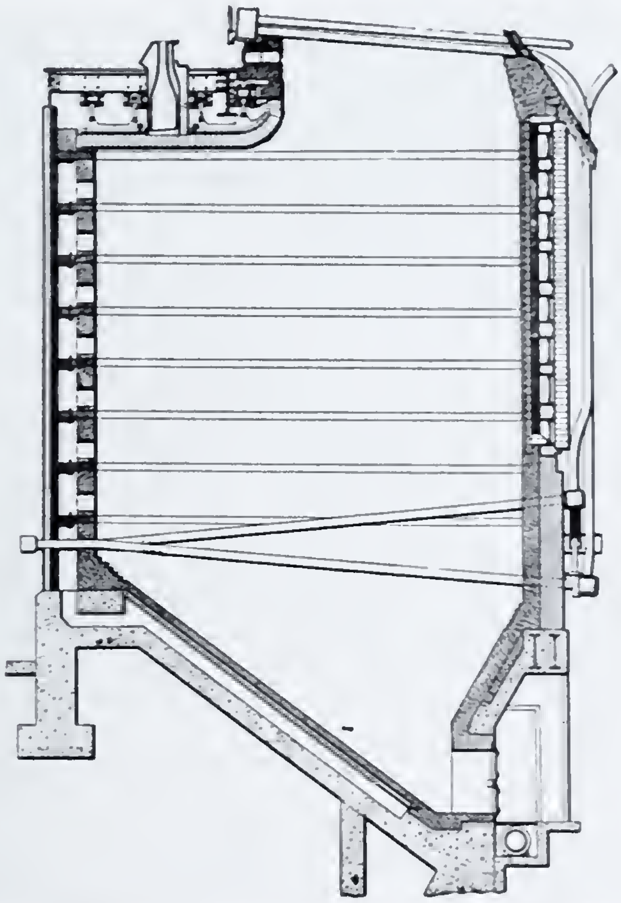

Fig. 15. Suspended Arch in Connection with Pulverized-Fuel-Fired Edgemoor Boiler.

wall, into the air space between the two front walls, through port openings in the front wall, to the furnace. In this way they get the advantage of preheated air for secondary air for combustion, and the cooling effect of the air to maintain the inner wall. The arches in an installation of this kind give excellent service and the maintenance is very low. In this construction, also, you will note the simplicity of the steel design. The construction around the burners makes it possible to repair any tile next to the burner castings.

Fig. 16 shows the under side of the arch installed at the Cahokia station of the Union Electric Light & Power Company, East St.

Louis, Ill. These arches are in connection with 1800-horse-power Babcock & Wilcox boilers fired with "Lopulco" pulverized-fuel equipment. This photograph was taken after the arch had been in service for several months, and the boilers operated with high CO_2 and at high ratings.

Fig. 17 shows the installation of a new type of boiler brought out by the Edgemoor Boiler Company. This installation is in connection with Fuller pulverized-fuel equipment at the plant of the Binghamton Light, Heat & Power Company. This installation has now been in

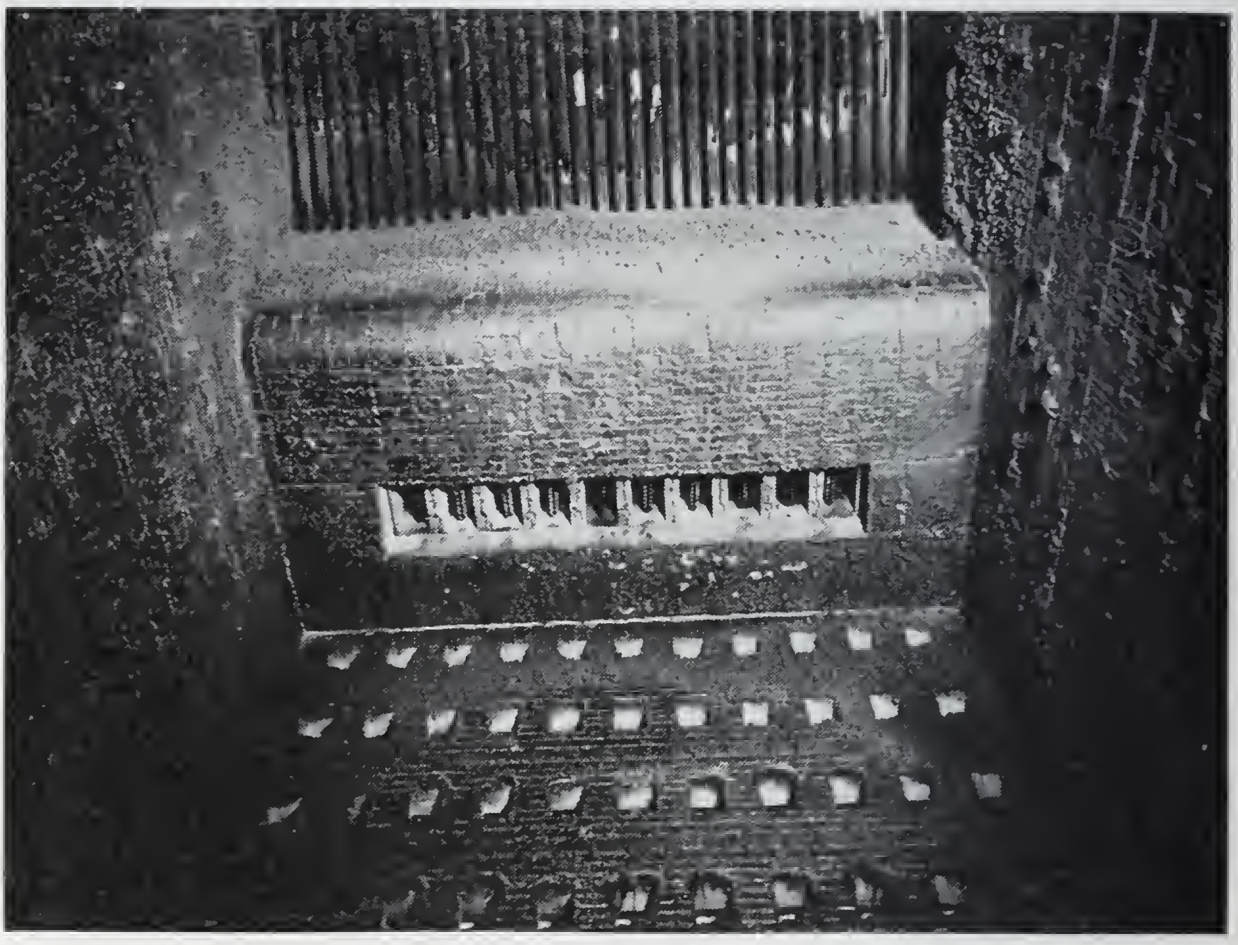

Fig. 16. Suspended Arch After Two Months' Service in 1800-Horse-Power, Pulverized-Fuel-Fired, Babcock & Wilcox Boiler.

for six months and has been operating at high efficiencies and capacities. The portion of the arch set on an angle provides for a considerable amount of heat radiated from the hot refractory material onto the boiler tubes. The hollow walls here are made up of a construction of castings and tile similar to the arch material. These walls are made in separate sections. Vertical castings are made in various heights. In this installation they were four feet, but on later installations they were cut down to two feet, three inches. Each vertical casting has a shelf on the bottom, which carries special tile.

Above this shelf the wall is of the same tile that are used in the arch. Between this shelf and the next vertical casting is placed a key tile that is merely set in place and not held by a casting. This provides a distinct separation between each two vertical sections of wall. In the other direction these castings are spaced 10.5 inches apart and carry a row of tile, so that in the horizontal direction every section of 10.5 inches is entirely separate from the other; and in the vertical direction every section of two feet, three inches is entirely separate. Each cast-

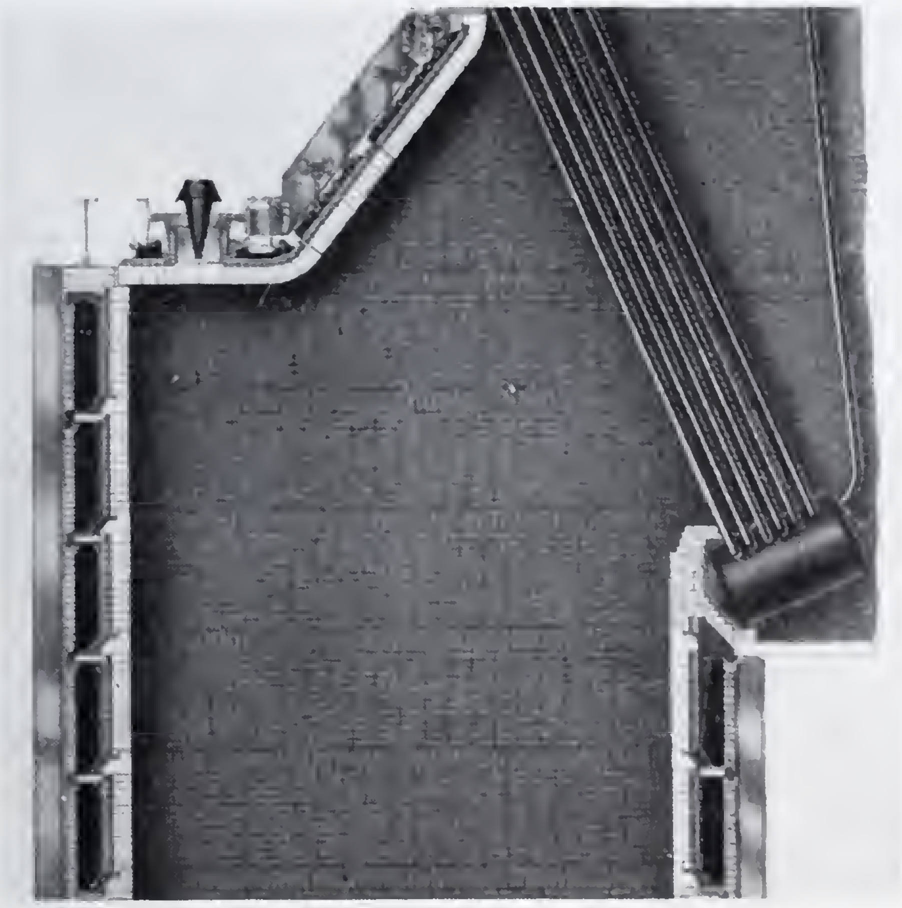

Fig. 17. Application of Suspended Arches and Suspended Wall in Connection with Pulverized-Fuel-Fired, Edgemoor, Single-Pass Boiler.

ing is hung on the web of a horizontal structural member and kicks against the flange of the structural member beneath. The castings are staggered so that this construction is possible. In other words, every vertical casting is suspended from the top and kicks against the structural member on the bottom. This makes a wall that is held in place by structural members and castings, and provides flexibility so that each section can expand or contract without disturbing any other. It also makes it possible to repair the wall in small sections, the same as can be done in the arch.

On the castings, a shelf is provided so that a tile or brick can be placed on top of this shelf and in this way make a distinct air compartment for each vertical section. As shown in the illustration, one course of brick or tile is placed on the shelf, thereby making a seal between the inner wall and the outer insulating wall. In this way each vertical section has a separate air compartment. Each compartment has a means of air supply, either through a door in the side wall or the rear wall, and this air passes between the inner and outer side walls to the space between the inner and outer front walls, and then through port openings into the furnace as secondary air for combustion. The main features of a wall of this kind are as follows:

1. The entire weight of the wall is supported from outside structural steel.

2. The wall is held so that it cannot fall inwardly or bulge.

3. Each section can expand or contract without disturbing another.

4. The wall can be repaired in small sections without disturbing any other section.

Several of these walls that have now been in service for some time are giving very satisfactory results with pulverized fuel and also with stoker firing.

Fig. 18 shows on a larger scale a detail of each section of the wall—how the castings are hung on the horizontal steel girders, and how the tile are held in place.

All of the preceding illustrations and data on arches have been shown in connection with boilers and stokers and pulverized-fuel equipment. The use of suspended arches in the steel industry, particularly as applied to industrial furnaces, has not been as fully developed as it has been in the boiler field. There are, of course, several reasons for this. First of all, there is no question but that in the steel industry there is always a crew of brick-masons that are on the pay-roll at all times, and these brick-masons are highly skilled in the art of building good substantial arches and brickwork of any nature. Another reason is that, with the possible exception of the firing end of heating furnaces and open-hearth furnaces, the temperatures encountered are not as high as in modern boiler practice. However, just as there were reasons for the gradual use of suspended arches in the boiler field, there are also reasons for the adoption of suspended arches in connec-

tion with industrial furnaces, and we find that within the last year or two considerable progress has been made in this direction. The general tendency seems to be toward wider heating furnaces, and this, of course, will incline engineers toward the consideration of suspended arches. Furthermore, brick-masons' wages seem to be going higher, and it is being realized by furnace men that suspended arches can be maintained and installed with less skilled labor and in less time than sprung arches, thereby to some extent cutting down their maintenance costs.

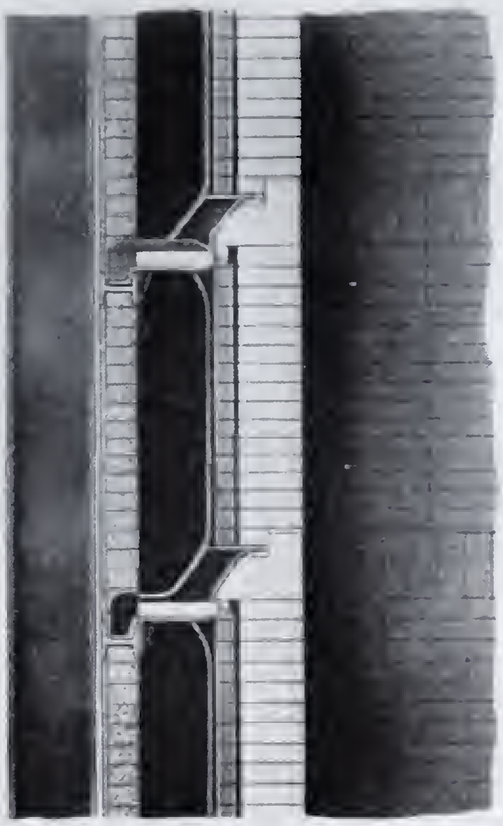

Fig. 18. Enlarged Section Showing Detailed Arrangement of Suspended Wall.

Fig. 19 shows a stoker-fired, continuous heating furnace in a steel-mill in the East. This installation has been in now for about eight months, and the operators claim considerable advantage from the use of the suspended arch. Their claim is that the heat is more uniformly distributed, which is desirable. The material heated is blooms of high-grade alloy steel. In the application of suspended arches to heating furnaces, it is desirable, of course, to arrange the supporting steel members so that they are supported on structural steel fastened to the buck-stays. In this way the arch is entirely inde-

pendent of the side walls. Either can be repaired without disturbing the other. In a construction of this kind, simplicity of design, as far as castings and tile are concerned, should be adhered to, and the least number of shapes possible should be used. In this particular case there are two shapes of tile for the entire arch. There is one important thing, as far as the application of suspended arches to continuous heating furnaces is concerned, which, in my estimation, should be brought out. I think that most of the furnace designers and engineers think it is advisable to keep the heat pretty close to the material. A crowned arch naturally will allow some of the heat to crowd toward the center, and hug the arch, passing off without giving much of its heat to the material. Another point is that, in connection with continuous heating furnaces, it has been found desirable to suit the slope and shape of the arch to the combustion requirements. This some-

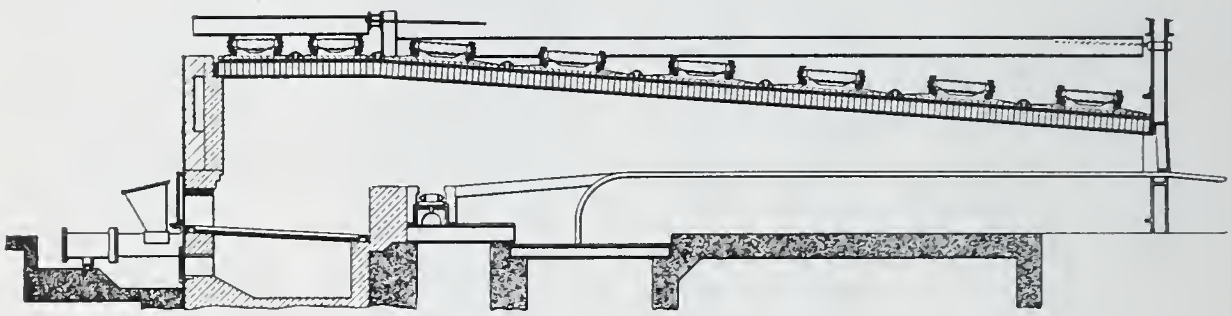

Fig. 19. Suspended Arch in Connection with Stoker-Fired, Continuous Heating Furnace.

times leads into complicated slopes and designs which are hard to meet with a sprung arch. As far as the suspended arch is concerned, it can be built to meet any shape or design required.

Fig. 20 shows a continuous heating furnace fired by pulverized fuel through the front wall at the plant of the Pollak Steel Company, at Marion, Ohio. They heat old rails from 105 pounds down, and split these up for light angle-irons or concrete bars. The coal used is Kentucky coal, low in ash and moisture, and the amount burned has never exceeded one ton per hour. This furnace is connected to a waste-heat boiler. This boiler is also fired with pulverized fuel, but utilizes the waste gases from the furnace. This is a 417-horse-power Geary boiler, operated at 175 per cent. of rating. The stack on the boiler is 34 inches in diameter and 30 feet high, and is connected to a Bailey motor-driven fan. The waste gases can be distributed either

through the boiler or through a stack 5 feet in diameter and 125 feet high. This arch has been in for a few months and, so far, very satisfactory results have been obtained from a heating standpoint. As far as maintenance on the arch is concerned, it is, of course, too early to get any data. However, from all appearances, it looks as though this arch will stand up for a considerable length of time. You will note that what I mentioned before in reference to the shape of the arch is well brought out in this furnace. This furnace is 18 feet, 4 inches

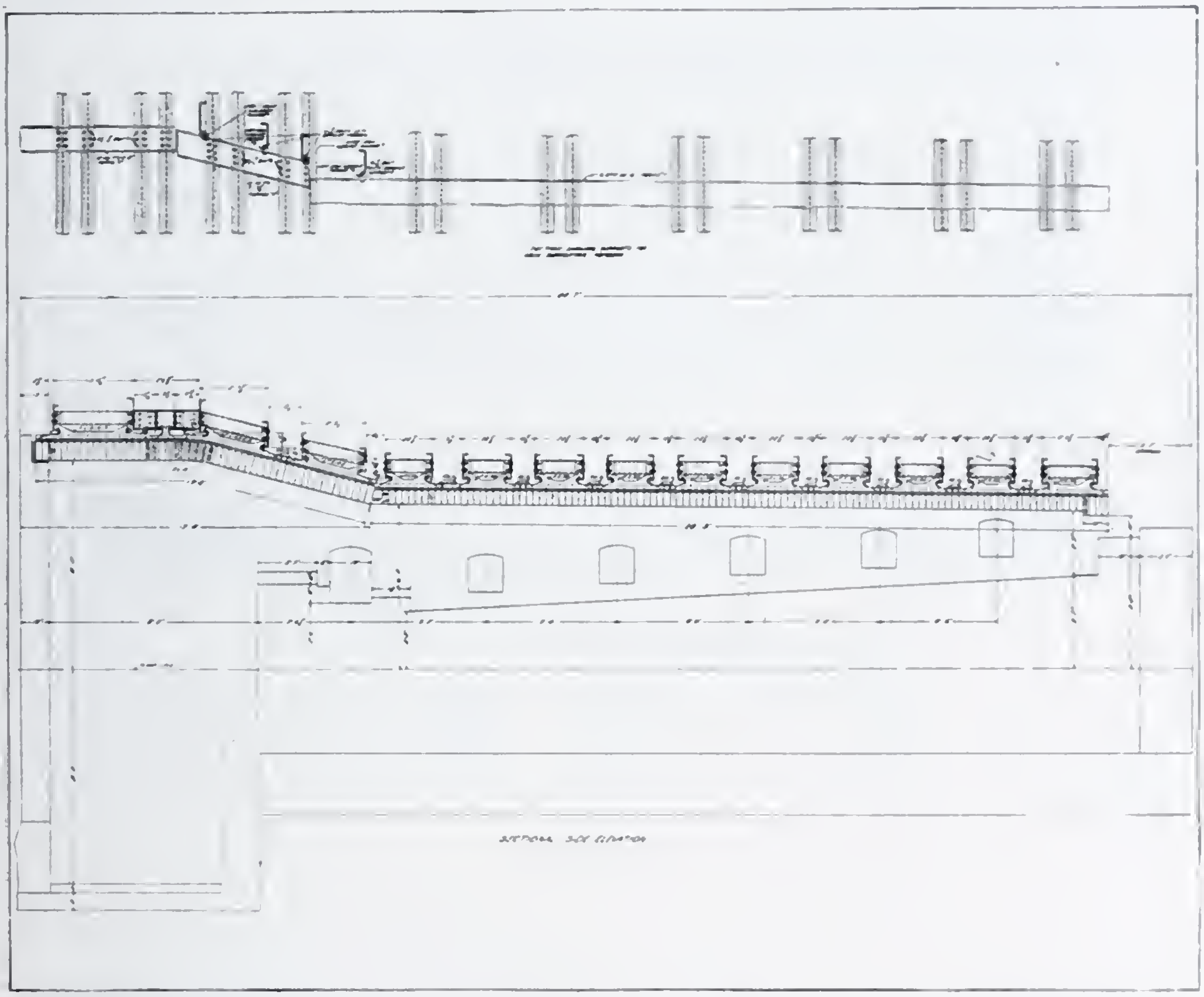

Fig. 20. Suspended Arch in Connection with Pulverized-Fuel-Fired, Continuous Heating Furnace.

wide, and all of the steelwork is supported on the buck-stays, so that there is no load on the side walls.

Fig. 21 shows the plan and front elevation of the arch in connection with the continuous heating furnace of the Pollak Steel Company. This illustration shows the arrangement of the steelwork for supporting the arch.

Fig. 22 shows a continuous heating furnace at the plant of the Alan Wood Iron & Steel Company It heats slabs from 1.5 to 3 inches

thick, in lengths of three feet. This furnace, as shown, was operated with pulverized fuel, and temperatures as high as 2850 degrees were noted. It was operated several months and very satisfactory results were obtained without any trouble whatever from the arch. However, about three months ago, it was decided to change from powdered coal to by-product gas, and the front end of the arch was lowered three feet without disturbing the remainder. This plant was shut down for several weeks and has just been started up again. The last

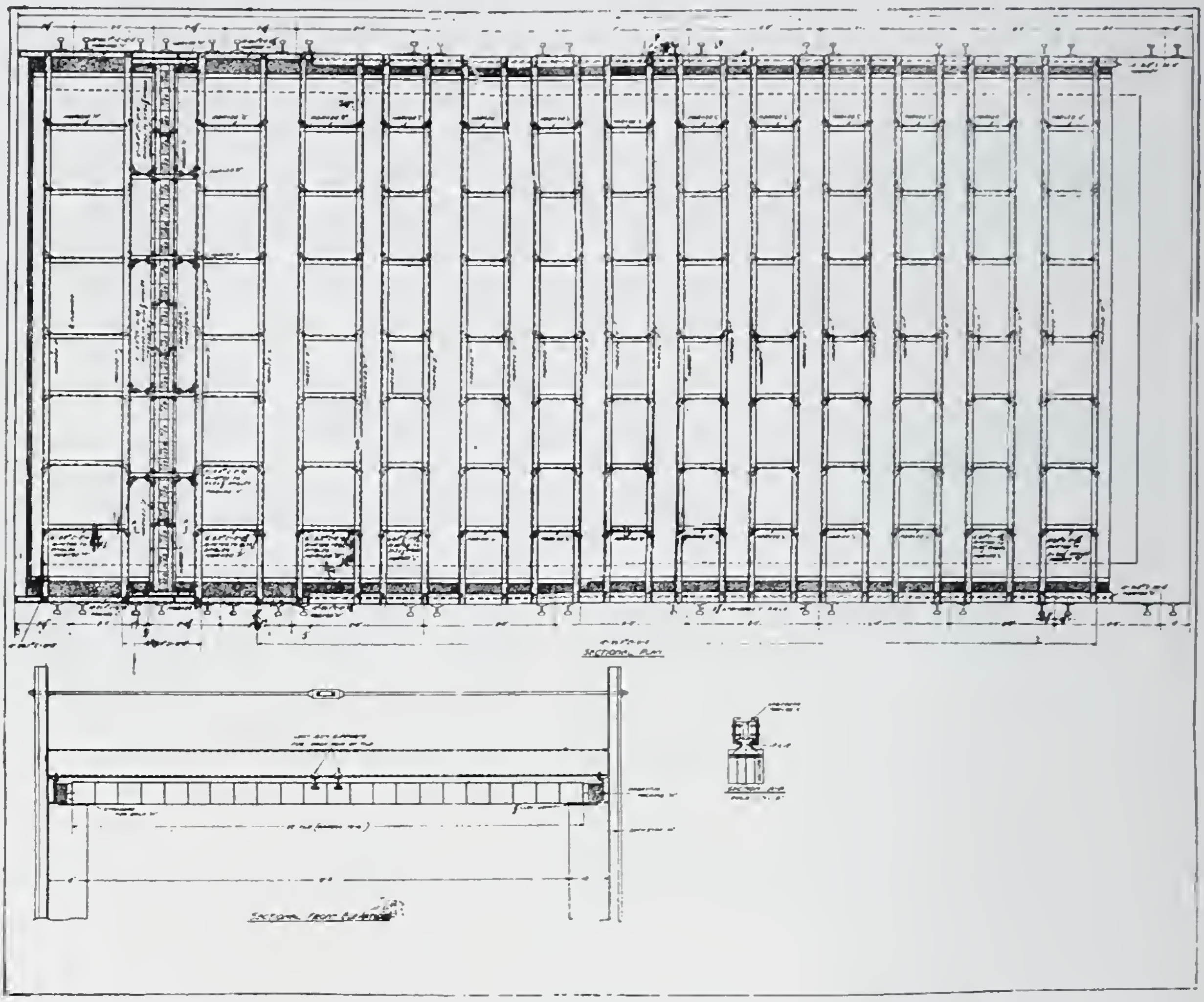

Fig. 21. Plan and Front of Suspended Arch in Connection with Heating Furnaces, Showing Arrangement of Steel Suspension Members.

report we received indicates that very satisfactory results are being obtained. Of course, this arch has not been in long enough to give us any real data regarding maintenance. However, we have an installation in connection with a continuous heating furnace in Wisconsin that has been in for over seven years. We have kept pretty accurate data on this installation, and it is based on this record that I make the statement that, as far as maintenance is concerned, suspended arches will give as highly satisfactory results in connection with heating furnaces as they are giving in connection with boilers.

Fig. 23 shows the design of soaking-pit cover that is installed at the works of the Donner Steel Company. It has been in service now since January 8. The method of raising and lowering this cover puts a considerable jar on the structure, so that we feel that this installation is a good test of how this design of soaking-pit cover will act in the ordinary plant. In other words, I have not seen, in my limited experience, any other means of removing a pit cover that will put any greater strain on the structure than this one has to withstand. When

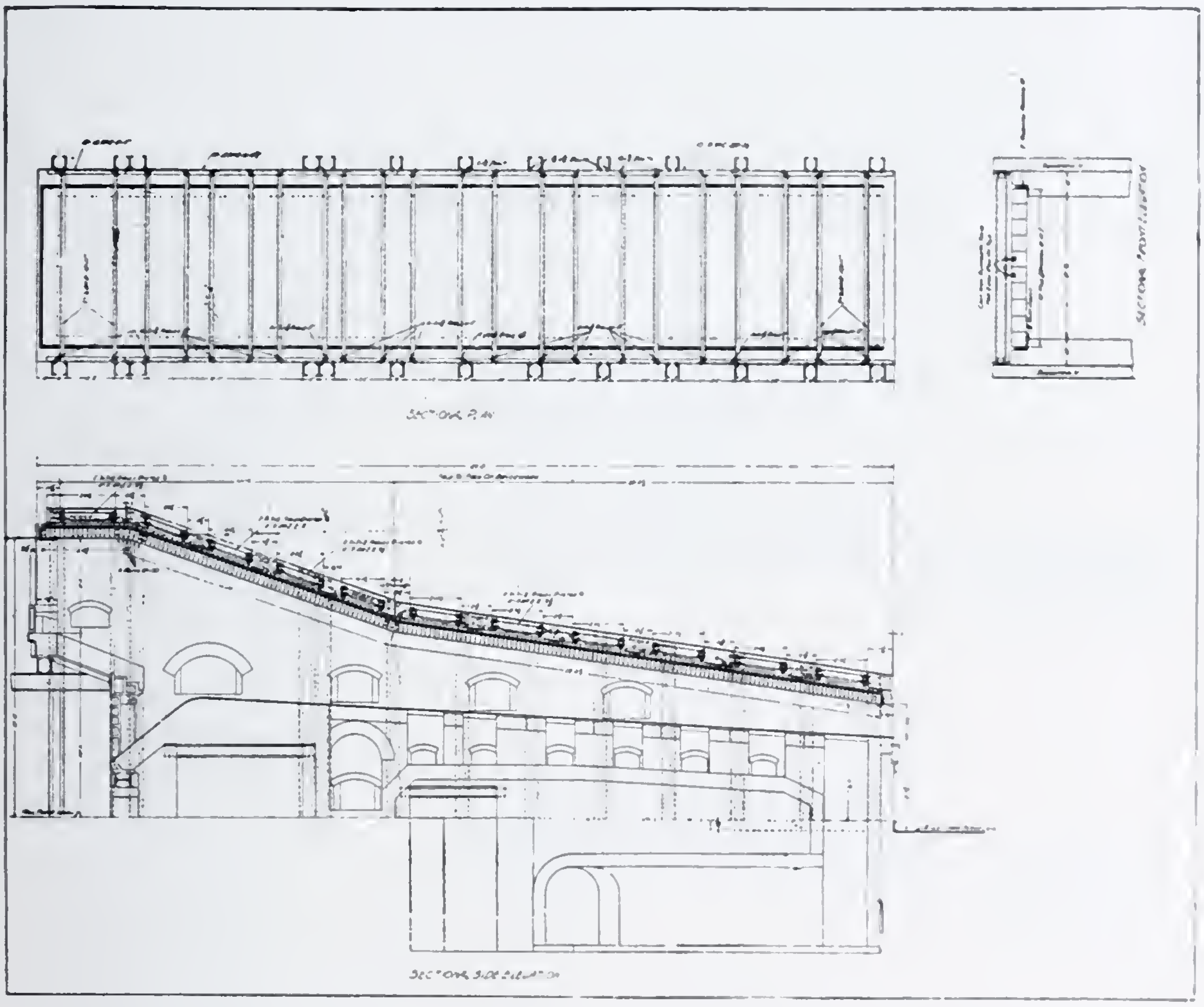

Fig. 22. Suspended Arch in Connection with Pulverized-Fuel-Fired, Continuous Heating Furnace.

it was first put in a little trouble was encountered due to an error made in figuring expansion joints. However, after it was retiled, this trouble was entirely eliminated, and, to date, this arch has shown no signs of deterioration. The castings have been red-hot for considerable periods at various times, but to-day are as good as when they were installed. The tile show absolutely no signs of being burned, and the structural frame is in perfect condition. They dropped an ingot on one of the side channels and bent the top flange of the channel. Other-

wise no harm was done. The steelwork is kept cool and at all times it is possible to put your hand on any part of the steelwork for a second or two. There is no discoloration of the steelwork that would indicate it had been overheated, and no warping.

Attention may be called to several features of a soaking-pit cover of this type:

1. The weight can be reduced by the use of this construction.
2. It is possible to use small shoe castings, so that even if they

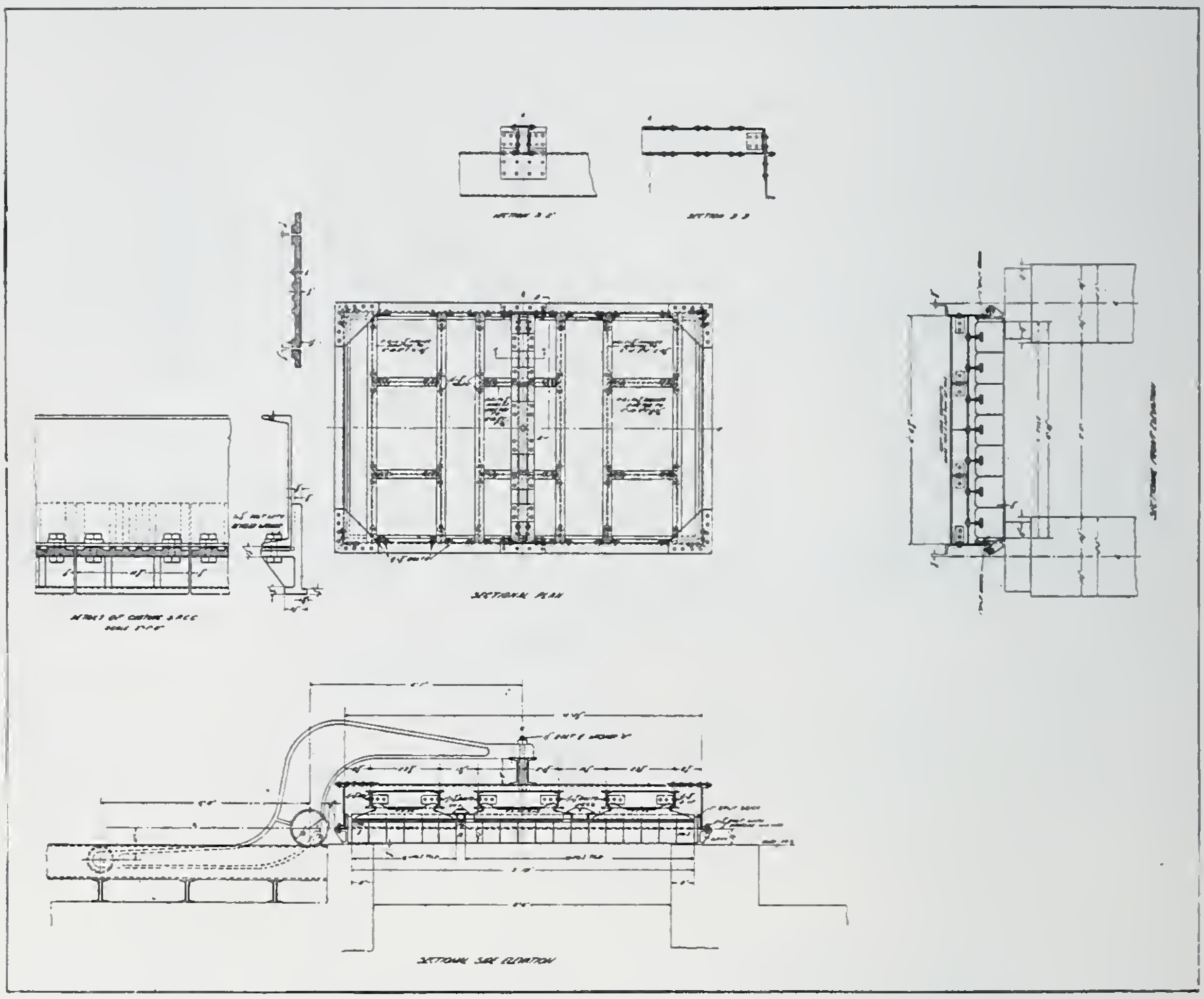

Fig. 23. Soaking-Pit Cover.

should burn up, the repairs are kept down to a very small item.

3. All of the tile are held in place by castings.

The jarring of the cover, due to being put on and taken off, therefore, does not materially affect the life of the refractory material. There is no question but that the continual jarring will sooner or later affect a crowned arch. Another item of importance is that, in view of the fact that the arch is perfectly horizontal, a better seal can be maintained between the walls of the pit and the under side of the

arch. It is very important that the best seal obtainable be provided, because any openings between the walls of the pit and the arch will allow the flames to impinge on the framework, which will result in very damaging effects. With certain kinds of fuel, particularly coke-oven gas which has a sharp cutting action, this point is very important.

The elimination of heavy and expensive castings, steel members, and highly paid brick-masons, who do their most careful work on the building of the crown, I believe warrants the consideration of a soaking-pit cover of this design. Such other points as the possibility of repairing this pit cover in small sections, and the fact that in most cases a material reduction can be made in the weight of the pit cover, should also prove very interesting. The installation for the Donner Steel Company is the first one we have ever made, but, to date, it looks as though it will prove highly satisfactory.

DISCUSSION

Mr. J. B. Crane, *Chairman*:* The question of arches is, of course, a very interesting one. I can remember in the old days when we tried to operate the sprung arch on the large boilers and had to use two arches with a post in the middle, and we got so we used to construct them double so that when the first one fell we would have the other to fall back on until we could get another boiler in operation.

The speaker laid a lot of stress on the question of weight of brick coming down to the point of temperature at which trouble would be experienced, yet in practically all the slides he showed he carried the weight of his arch on the brickwork instead of carrying that steel support of the arch to the side steel. When he came to his heating furnaces he did not do that, but in the boiler structures he did show that. If it is wise to take it off in one case, it would seem to be wise in general. A lot of trouble is experienced unless care is taken in the design.

As to ventilation, that matter was brought to our attention very forcibly a little while ago. A boiler with a flat arch after six months' operation developed trouble. The steelwork on the upper part of the arch had given way and the arch had opened up at the bottom. We sent a man to find out what was the trouble and he discovered that after we left they had put a lot of loose asbestos on top of the arch and insulated the steelwork so that no air got to it and, consequently, it got so hot it allowed the arch to sag at the middle.

I see Mr. Stoop, of the Wheeling Steel Company. We should be glad to hear some of his experiences.

Mr. W. J. Stoop:† I have not had enough experience to express myself. What we have done is just for ourselves and not for the public.

Mr. J. B. Crane, *Chairman*: Haven't you put in some water-cooled arches?

*Vice-President, George T. Ladd Co., Pittsburgh.
†Wheeling Steel Co., Wheeling, W. Va.

Mr. W. J. Stoop: Yes, we have put in air-cooled and water-cooled, but, so far, we have not had enough experience for a thorough demonstration; but we are getting a lot of information and I think we shall have something to tell pretty soon.

Mr. R. L. Ehmann:* The first thing I want to do is to compliment the speaker on his very excellent paper.

There are a few thoughts I wish to add regarding the experience of the American Arch Company.

We have specialized on industrial furnaces and, to date, have a large number of such furnaces installed, ranging in width from 5 to 33 feet, and in length from 12 to 72 feet. The furnace 32 feet in width, I believe, is the widest furnace using flat hung roofs in the country.

The speaker mentioned the open-hearth furnace as a possibility for suspended roofs, but gave no information thereon. Close to two years ago the American Arch Company made an installation of a suspended roof on a 70-ton, basic-open-hearth furnace. Our success with the suspended roof on this open-hearth furnace has, in our estimation, been remarkable and we believe well worth investigating.

The above mentioned furnace is used in making ingot iron, which service, I believe, is recognized as being very severe. Our first roof was in service for 365 heats, two complete campaigns being run. The second roof was in service 428 heats, three campaigns being run. When the roof was renewed it was conceded that it was probably still good for at least 50 more heats. We believe that our work on the open-hearth furnace with suspended roofs has made a record which should be worth considerable to the steel industry.

The open-hearth roof mentioned above was not flat. We do not believe in a flat roof for this work, at least not with present design and operation of furnaces in common use in this country. The roof is entirely suspended, and expansion and contraction are taken care of by means of floating skews and springs in such a manner as to maintain, at all times, a tight arch without exerting detrimental pressure on the roof tile, as this has a tendency to lower the softening point. The expansion on a 14-foot span averaged about two inches. This

*District Manager, American Arch Co., Pittsburgh.

expansion was measured from time to time during the operation of the furnace.

There is one point the speaker did not make entirely clear to me, and that is in regard to the concave-convex arch. He stated that with this arch they were able to get more heat rays reflected to the point of ignition than with any other type.

I believe if we superimposed an arch of proper design on the concave-convex arch, striking a tangent point on the rear nose and sloping the main arch downward toward the ignition arch, so that it would meet the 17-inch ignition arch about ten to twelve inches above the top row of ignition tile, more rays would be reflected towards the gate to assist in ignition than could be obtained with the concave-convex arch, which acts like a reflector, tending to focus and throw the radiant heat towards the bridge wall.

Mr. E. Rahm, Jr.:* Referring to the Pollak Steel Company installation on the continuous billet-heating furnace at Marion, Ohio, I had the pleasure of assisting in the design of the pulverized-coal lay-out on both the furnace and the boiler. Owing to a very high sprung arch, this installation had a rather high rate in pounds of coal per ton of steel. Since installing a flat arch over this furnace and lowering the height of the arch they have almost doubled the capacity of the furnace. I have just received a letter from Mr. E. J. Paque, general works engineer, stating that the coal consumption was already lowered 15 per cent. Owing to the fact that there is a waste-heat boiler in connection with this furnace, they will probably never find it advisable to work for the maximum efficiency of operation, which would be less than 200 pounds of coal per ton of rails.

Referring to the arch over the stoker-fired boiler at the Philo plant, the idea of introducing air through the arch to prevent stratification of gases and induce turbulence in the furnace seems to be a new one and well worthy of being followed out to a greater extent.

Referring to Mr. W. J. Stoop's remarks about the air-cooled and water-cooled arch , I believe he has been a little modest about this. I have been an interested spectator of the development of this arch for a number of years. In the case of the water-cooled arch, I understand that there is danger of the pipe sweating a little when not in operation.

*Sales Engineer, Erie City Iron Works, Pittsburgh.

The air-cooled arch seems to have a great many possibilities. In these days when preheated air is becoming fashionable in connection with steam-generating installations, this arch offers another place on the boiler in which air can be preheated. The air can be either forced or drawn through the arch. The life of the tile is thereby increased, while the heat recovered can be used in either stokers or pulverizers to assist in flame propagation, or in drying the coal before pulverizing. It seems that this arch is bound to meet with considerable favor and to merit further tests and investigation as the art of combustion progresses. Mr. Stoop is certainly entitled to a great deal of credit for the pioneer work that he has done and is doing in this direction.

MR. H. C. CRONEMEYER:* I believe the speaker said that the use of coke-oven gas introduced a new problem.

MR. LOUIS ELLMAN: I said that a cutting action was set up.

MR. H. C. CRONEMEYER: What causes that cutting action?

MR. LOUIS ELLMAN: High hydrogen, probably.

MR. A. E. BLAKE:† It occurred to me that by the elimination of tie-rods and buck-stays you get very improved construction with many types of ordinary furnaces, regardless of size or temperature requirements. I wonder if much progress has been made in that line or if the suspended-arch people concentrate on boilers and heavy-duty continuous furnaces such as were described.

MR. R. W. ANDREWS:‡ The only thing that occurs to me is that the discussion has been mainly upon the efficiency and reasons for a flat arch and not so much on the details of construction or perhaps the reason for a different type of construction. For instance, Mr. Ellman's is the single-suspension type; but there are also the double-suspension type, the air-cooled-support type, and the water-cooled type, and I should think the discussion of flat arches would bring

*Designer, Jones & Laughlin Steel Corporation, Woodlawn, Pa.
†Pittsburgh Representative, U. G. I. Contracting Co.
‡Andrews-Bradshaw Co., Pittsburgh.

out those features. I know nothing about them myself, I am just wondering.

Mr. V. P. Griffin:* On account of expansion being cumulative from the center of an arch towards the sides and ends, I would like to know if any provision is made to take care of this expansion in extra wide and extra long arches.

Mr. J. B. Crane, *Chairman*: There is one other question I want to ask in regard to the sealing of the arches after they are installed. Do they put any grout on or leave it open to admit what air does go in?

Are there any other questions? If not, I will ask Mr. Ellman to reply to the questions that have been asked.

Mr. Louis Ellman: As for keeping the weight of the arch off the side walls, I neglected to explain that in most cases of pulverized-fuel boilers, particularly of wide dimensions, the structural steelwork is supported on the outside steelwork. We try, wherever possible, to support the structural steelwork of the arches on the outside steelwork. In the final analysis it is up to the customer, and in most instances he does not care to spend the additional money.

Mr. Ehman's remarks about the open-hearth furnace I think very interesting. I think his company should be congratulated because, as far as I know, they are the first to make a success of a suspended roof on an open-hearth furnace. We are putting one in in connection with a 100-ton, open-hearth furnace for the Donner Steel Company. It will be some time before this arch is put in service. The arch we are recommending is suspended, but is not a flat arch.

As regards the heat rays reflected from the convex-concave arch, I did not quite follow the exact design of the arch Mr. Ehman described, but I think he brought the design of it as near the convex-concave as he could, and the more nearly you approach it the more intense the reflected heat will be.

Mr. Rahm's question about the distance between the arch and the boiler I cannot answer offhand, but I shall be glad to give it to him. I shall have to look it up to-morrow.

*Combustion Engineer, Duquesne Light Co., Pittsburgh.

As to arches in small furnaces, we have a good many in connection with all kinds of furnaces. The matter of getting them in small furnaces is a sales proposition. Perhaps we can be blamed for not being better salesmen; otherwise, we might have more of them in small furnaces. In any event, we are trying to sell them.

As for the discussion of the different types of suspended arches, I often question whether an engineering society of this kind is the place to offer that. I did not try, or at least I did not intend to try, to discuss different makes of arches. I tried to confine my statements to suspended arches. I do not know of anything that was illustrated here that could not be duplicated by any other arch manufacturer, with the possible exception of the convex-concave design. I think a paper of this sort perhaps is better received if we do not discuss the individual merits of the different arches. If you are interested, you will be pestered by salesmen willing to give you the merits and demerits of the various types.

In the expansion of wide arches—and that almost ties itself up with Mr. Crane's question as to how the arches are grouted in—the grouting of the arches is always dependent on the service. If you are using arches in connection with furnaces with forced-draft, chain-grate stokers burning coke breeze, where there is a tendency to carry pressure in the furnace, it is better to dip the brick and then tap them together to make as tight a job as you possibly can to keep the action of the flame from getting in between the joints. If you are using arches in connection with pulverized-fuel boilers or with natural-draft, chain-grate stokers burning bituminous coal—in fact, any place where a suction in the furnace is probable—I like to butter the brick and then get on the under side and point them up with a thick fire-clay and then get on top and pour a thin grout in between the joints. That gives a flexible arch because you have sufficient flexibility to take up some of the expansion.

I do not believe any one way of installing an arch will suit every condition. I know it will not. I have seen installations which were put up without any fire-clay and they gave excellent results. I have seen others giving very poor results. I do know that for service where you are likely to encounter pressure the best thing to do is to get the arch as tight as possible. In other installations, let a little air get in between, or put in a thicker joint and depend on its taking up some of

the expansion. On some arches that have been used in boilers about 25 feet wide, we have allowed a space of about a quarter-inch between the tile at one or two points, and have then covered these spaces up with loose brick. The idea was to provide this means for expansion. However, in checking them up, we found that these quarter-inch spaces were never closed up. We therefore came to the conclusion that with the use of three-inch tile there are a good many joints and each one of these joints takes up a certain amount of expansion. These, together with the expansion spaces we allow where the arch laps over the side walls, seem to provide sufficient expansion, so we have never encountered any difficulty from this source. We have a good number of arches over 20 feet wide, and they have all proved very satisfactory.

FUNDAMENTALS IN THE CONDITIONING OF BOILER WATERS*

By R. E. Hall†

OUTLINE

INTRODUCTION

Of the problems confronting the engineer responsible for the generation of steam those which have their genesis in the type of water used are (1) the prevention of adherent scale formation on supply lines and evaporating surfaces; (2) the inhibition of corrosive action on the surfaces with which the water makes contact; (3) the disposal of the sludges produced in the boiler water; and (4) the delivery of dry steam of a purity such that the non-condensable gases therein will not cause trouble from corrosion when the steam condenses. Any complete system of boiler-water conditioning must take cognizance of these four phases, and must realize that they are closely interrelated and require definite chemical and mechanical means for their control.

For almost four years the United States Bureau of Mines and the Hagan Corporation of Pittsburgh have been co-operating‡ in an investigation of boiler-water conditioning. The Bureau has paid particular attention to the first two factors and the necessary chemical control in all of them, while the Hagan Corporation has devoted itself especially to the development of the mechanical features requisite for an inclusive system.

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†Physical Chemist, Pittsburgh Experiment Station, U. S. Bureau of Mines.
‡The co-operative agreement was signed January 18, 1922.

Through the co-ordination of laboratory data obtained at the Pittsburgh Experiment Station and practical operating data acquired from plants in all parts of the United States, many basic facts have been brought to light. This paper will briefly summarize some of the fundamental features which must be emphasized in conditioning water for steam generation.

RELATION OF WATER SOFTENING TO BOILER-WATER CONDITIONING

The industrial uses of water may be divided into two classes: (1) those in which the characteristics of the water itself are the thing desired; and (2) those in which its transformation into another form is the primary requisite. As examples of the former, the use of water for ordinary household or laundry, or for cooling purposes may be cited; of the latter, its use in the manufacture of artificial ice or the production of steam.

The first major distinction between water softening and boiler-water conditioning is the fact that the former deals only with the dilute water leaving the softener; whereas, in the latter, attention must be focused upon the concentrated boiler water at all times. When water is to be used for ordinary household or laundry purposes, the removal of calcium, magnesium, and iron to the limit of their solubility as carbonate or hydroxid is the essential thing desired. No thought need be given to the other constituents present because the primary use is as water and not as some other modification. These uses fall strictly within the significance of water softening, for Webster's New International Dictionary defines a soft water as one "characterized by the practical absence of substances, as calcium and magnesium salts, which prevent formation of lather with soap." The criterion of efficiency in water softening is thus the extent of the removal of calcium and magnesium from a water, and the results are frequently expressed in terms of degrees of hardness as determined by the soap test.

In ice making and steam generation, however, the primary purpose of its use is not as water, but to transform it into ice or steam. Either of these uses involves the production of a pure product and the concentration of the impurities in the remaining fraction of the water. In ice making this concentration of impurities is not a matter of such

great importance, because the pure primary product forms at the metal surfaces where the transfer of heat is desired and the surfaces therefore do not become contaminated by a deposition of scale. Further, the temperature range to which these surfaces are subjected is slight. In steam generation, however, the evaporating surfaces are continually in contact with the concentrated boiler water which, according to the pressure of operation, may be at a temperature of 100 to 225 degrees C. (212 to 437 degrees F.), or even higher. At these surfaces, also, the steam forms and thus favors deposition of insoluble solids upon them. It is essential, therefore, that the condition of the boiler water be controlled at all times.

Because the primary function in steam generation is changing the water into steam, thereby increasing the concentration of sodium sulphate and other salts in the unchanged water, and because the waters in different boilers are maintained at different temperatures and are continually in contact with the evaporating surface, treatment of the water for the prevention of scale deposition becomes a function of (1) the operating pressure of the boiler, and (2) the control of the concentration of the sulphate, carbonate or phosphate, and hydroxid concentrations in the boiler water, regardless of the removal of any calcium and magnesium salts. Thus it is apparent that water softening is a much less inclusive term than boiler-water conditioning. As a matter of fact, water softening is related to boiler-water conditioning only because on the one hand calcium and magnesium soaps happen to be but slightly soluble, and on the other calcium bicarbonate is unstable, and calcium sulphate and presumably magnesium silicate have solubilities which decrease with temperature increase.

The second distinction between water softening and boiler-water conditioning lies in the different types of control demanded by different operating conditions. Fig. 1* shows in diagrammatic form the different conditions which must be taken into consideration in conditioning boiler waters.

First, there are those surfaces in contact with water below steam temperature—that is, those at which no evaporation is occurring—at which corrosion may present the greatest problem, although scale deposition may occur also.

*The author wishes to acknowledge the assistance of Mr. T. A. Peebles, of the Hagan Corporation, in the preparation of this diagram.

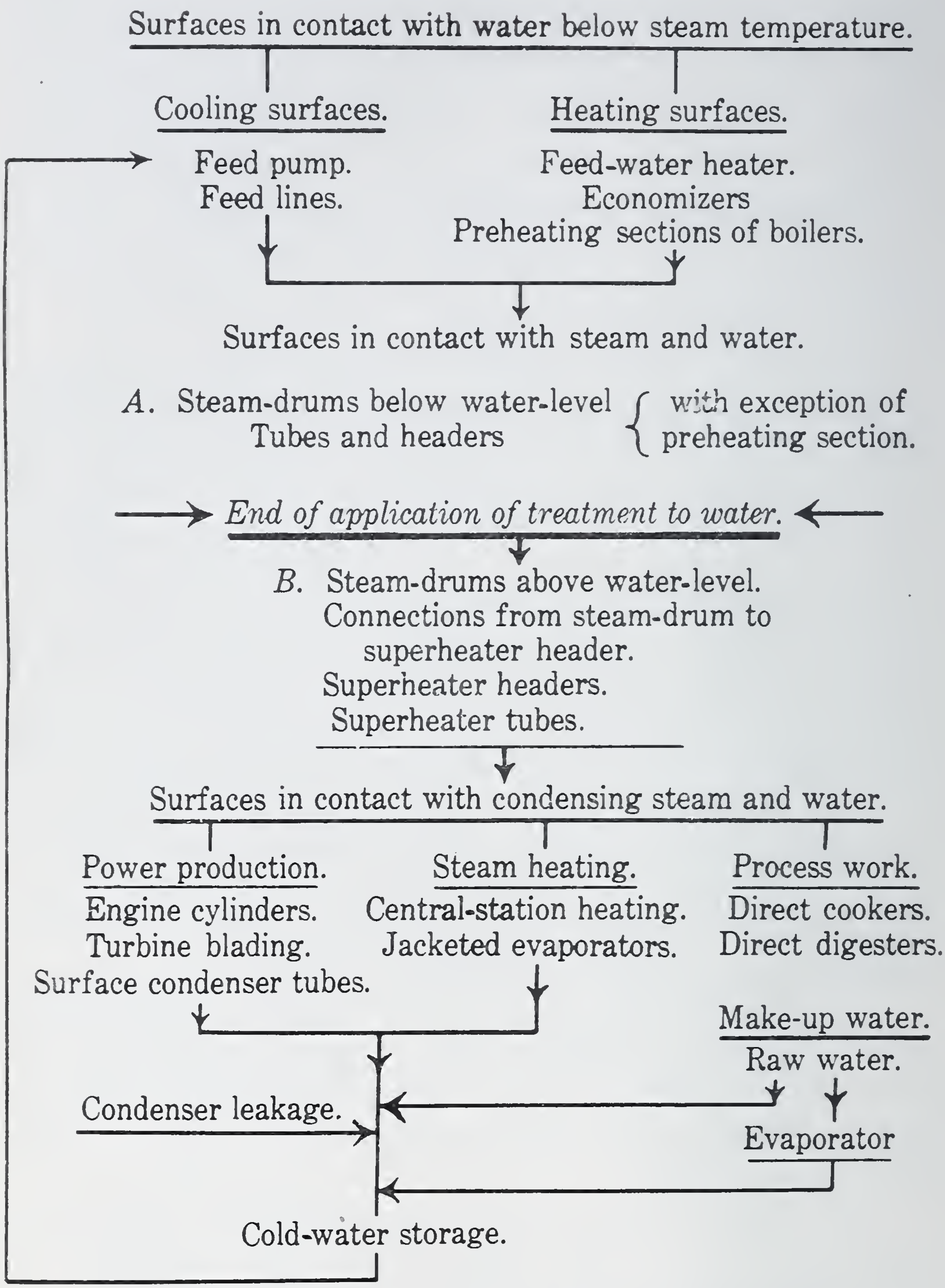

Fig. 1. Surfaces of Steam Generating and Consuming System.

Second, there are those surfaces in contact with steam and water. These may be subdivided into A, those in direct contact with the boiler water—that is, the evaporating surfaces—and B, those which are in contact with boiler water because of entrained moisture in the steam. It should be noted that with A comes the end of the possibility of treating the water. Whatever is required for the protection and economic operation of the entire system must be done prior to this point.

Third, there are those surfaces in contact with condensing steam and water. For the purposes of power production and steam heating greatest interest centers in the types of solid deposits which may be caused by the steam and the corrosive action of any non-condensable gases therein. In process work, however, the chemical effects of entrained solids and of non-condensable gases are of moment. The control of the character of the steam lies in the conditioning of the boiler water.

One other point in this diagram stands out prominently. Whereas the raw water used for make-up may be treated by an outside system or by an evaporator, the condenser leakage has a clear path to the boiler, and only in a control held on the boiler water itself can its effects be obviated.

The process of conditioning the boiler water, therefore, must be made to control not only corrosion and the formation of scale on the heating and evaporating surfaces, but must also regulate the moisture and sludges which are entrained in the steam and those non-condensable gases in the steam which will produce corrosion at any point where condensation occurs.

DEPOSITS RESULTING FROM THE EVAPORATION OF NATURAL WATERS

It is possible, first of all, to exclude some substances that occur in natural waters from any consideration in relation to deposits in the boiler. In Table I are listed the solubilities of those constituents which represent the more soluble substances in natural waters and which cause no trouble, therefore, by depositing as scales or sludges. Thus in a boiler operating at 200 degrees C. (392 degrees F.), if less than 700,000 parts per million of calcium chlorid or 300,000 parts per million of sodium chlorid or sulphate is present in the boiler water,

TABLE I—SOLUBILITIES AT VARIOUS TEMPERATURES OF SOME OF THE MORE SOLUBLE CONSTITUENTS IN NATURAL WATERS, PER CENT. [a]

Temperature	Calcium chlorid	Calcium nitrate [b]	Magnesium chlorid	Magnesium nitrate	Magnesium sulphate	Sodium chlorid	Sodium nitrate	Sodium sulphate	Sodium carbonate
0	37.3	50.5	34.6	40.0	20.4	26.3	42.2	4.2	6.6
20	42.7	56.4	35.3	42.6	26.2	26.4	46.8	16.2	17.6
40	53.5	66.2	36.5	45.9	31.3	26.7	51.2	32.5	33.2
60	57.8	78.0	37.9	49.4	35.5	27.1	55.5	31.2	31.7
80	59.5	78.3	39.8	53.7	38.6	27.6	59.7	30.2	31.1
100	61.4	78.5	42.2	....	40.6	28.2	63.5	29.8	31.0
120	63.4	78.8	46.2	....	40.2	28.8	67.9	29.5	....
140	65.6	78.9	47.5	....	36.7	29.6	....	29.6	....
160	69.0	79.1	50.4	....	30.8	30.4	....	29.8	....
180	75.0	....	55.3	....	23.5	31.0	....	29.9	....
200	75.7	....	....	....	....	31.5	....	30.0	....

a To express in parts per million, multiply by 10,000.

b The data for calcium nitrate were taken from "Tables annuelles de constantes et données numériques de chimie, de physique et de technologie," v.3, 1914, p. 324. All other data were taken from Landolt-Börnstein "Physikalisch-Chemische Tabellen," Ed. 5, 1923.

none of these substances will be deposited in the solid form. (Deposits in superheater headers and tubes, which result from the *complete* evaporation of boiler water entrained in the steam, are certain to contain sodium sulphate and chlorid, and other salts highly soluble in water.)

Table II presents the effects resulting from the less soluble constituents in the feed-water.

TABLE II. FEED-WATERS AND THEIR RESULTANT SCALES AND SLUDGES

A. Pittsburgh. 500-horsepower Heine boiler. Operating pressure, 150 to 160 pounds.

Feed-water, parts per million

Source	SiO_2	Fe	Ca	Mg	Na+K	HCO_3	SO_4	Cl
Monongahela River	5	2	36	5	14	12	126	8

Boiler water

Steam drum.......	13	2	30	36	142	10	387	81

Boiler scale, per cent.

Source	SiO_2	Fe_2O_3	CaO	MgO	SO_3	CO_2	Moisture at 105 degrees C.	Net ignition loss	Microscopic analysis *c*
Tubes........	1.5	2.2	36.6	1.6	54.5	....	0.5	1.5	Anhydrite

Boiler sludge
(Found only when the calcium content of the feed-water is very high)

Mud pan and upper tubes..	0.7	0.8	39.7	1.8	56.3	....	*a*	1.2	Anhydrite *b*

B. Washington, Pa. 1000-horse-power Stirling boiler. Operating pressure, 110 to 120 pounds.

Feed-water, parts per million. So far as possible, no city water was used

Source	SiO_2	Fe	Ca	Mg	Na+K	HCO_3	SO_4	Cl
Well..........	29	5	98	16	198	654	128	52
Well..........	5	3	152	18	131	551	96	55
Well..........	16	15	82	53	82	517	84	64
City water.....	6	3	44	5	16	81	60	26

Boiler scale, per cent.

Source	SiO_2	Fe_2O_3	CaO	MgO	SO_3	CO_2	Moisture at 105 deg. C.	Net ignition loss	Microscopic analysis
Preheating section....	1.5	1.0	52.9	1.8	0.8	40.1	0.1	2.0	Aragonite
Steam drum....	17.1	1.8	26.1	22.8	0.9	20.2	1.6	9.4	Calcite; hydrous magnesium silicate

Boiler sludge

Mud pan at feed-water inlet	0.7	1.2	51.1	3.7	0.4	42.1	0.1	1.0	Calcite
Mud-drum..	6.9	1.3	40.8	12.8	1.6	31.2	0.7	5.5	Calcite; hydrous magnesium silicate

C. Mesa County, Rocky Mountains, Colorado.

Feed-water, parts per million

SiO_2	Fe	Cl	Mg	Na	HCO_3	SO_4	Cl
21	1	109	59	74	363	356	6

Scale and sludge from a return tubular boiler operating at 100 pounds pressure, per cent.

Type	SiO_2	Fe_2O_3	CaO	MgO	SO_3	CO_2	Loss at 105 degrees C.	Net ignition loss	Probable components
Scale.......	7.8	1.1	28.9	17.1	23.2	11.5	1.1	8.6	Anhydrite; calcite; brucite; hydrous magnesium silicate
Sludge.....	5.0	1.2	27.7	21.3	32.4	4.1	0.1	7.4	Anhydrite; calcite; brucite; hydrous magnesium silicate

Scale from a locomotive boiler operating at 180 pounds pressure

Scale.......	6.2	0.7	33.2	10.0	44.1	2.0	0.5	3.2	Anhydrite; hydrous magnesium silicate. Very little calcite and brucite

a Analysis made on sample dried at 105 degrees C.

b Determined from the chemical analysis.

c Microscopic analyses by H. E. Merwin, Petrologist, Geophysical Laboratory, Washington, D. C.

In section A of Table II are presented a characteristic boiler water and boiler scale resulting when Monongahela River water is evaporated in a boiler operating at 150 to 160 pounds pressure. This water (as well as the Ohio and Allegheny river waters, and in fact many surface waters in the industrial sections of this country) is distinctly a sulphate water—that is, it is high in sulphate (SO_4) and relatively low in bicarbonate (HCO_3). The chlorid (Cl) content has a minor influence on the type of deposition which occurs. The amount of concentration represented in the boiler water is shown by the ratio of sodium (Na) and chlorid in the boiler water to sodium and chlorid, respectively, in the feed-water. This ratio is approximately 10. The surprising thing, however, is that the calcium (Ca) content of the boiler water is *less* than that of the feed-water and the sulphate ratio is only 3.1; but when one observes the composition of the scale and finds it made up of more than 90 per cent. calcium sulphate (anhydrite), the explanation is apparent. The boiler water has been continually saturated with calcium sulphate and has been steadily depositing solid crystals thereof as impervious adherent scale on the evaporating surfaces. The sludge, also mainly calcium sulphate, is present in boiler waters of this type only in protracted dry spells when the calcium content of the feed-water is especially high; or when the feed-water is normally exceedingly high in sulphate, as in a mine water or the water from the Youghiogheny River. The water considered in section A of Table II gives no sludge or scale in the feed-water heater or the mains carrying the heated water to the boiler—that is, at points where no evaporation occurs.

Section B of Table II represents the results from evaporating a water high in bicarbonate and silica (SiO_2). Two types of scale result which are radically different from the calcium sulphate scale heretofore considered. In the section of the boiler where heating occurs without evaporation, both sludge and scale formed; the sludge in the mud pan of the boiler was almost pure calcium carbonate (calcite); and the scale which formed on the preheating section was calcium carbonate, but in the form of aragonite. This type of scale is relatively soft and water permeates it readily.

The scale which formed on the evaporating surfaces was quite different in physical characteristics. It was very hard, and while relatively thin was quite impervious to water. It contained more than

45 per cent. of calcite, practically no calcium sulphate, but a relatively large amount of hydrous magnesium silicate (between 35 and 40 per cent.). It is the presence of the last substance which is the dominating factor in scale formation of this type.

The sludge in the mud-drum was made up of a fine powder and broken chips of scale. The chemical analysis made of the mixture showed higher content of calcite and lower content of hydrous magnesium silicate than the adherent scale. Microscopic analysis, however, showed that the chips were very high in hydrous magnesium silicate and the powder was largely calcium carbonate.

The feed-water of section C of Table II is high in both bicarbonate and sulphate, so that the effects noted in both sections A and B might be expected to be present. This is the case, for in the return tubular boiler operating at 100 pounds pressure both scale and sludge contained calcium sulphate, calcium carbonate, hydrous magnesium silicate and magnesium hydroxid. In the boiler operating at 180 pounds pressure, however, the scale was composed mainly of calcium sulphate, though some hydrous magnesium silicate was present. This again is as it should be, for calcium sulphate is less soluble at the higher than at the lower operating pressure, hence the possibility of its removal in solution in the blow down was less.

We may conclude therefore, in general, (1) that any scale formed in the feed-water lines and preheating sections of a boiler will be relatively soft and porous and will consist mainly of calcium carbonate; and (2) that two distinct types of hard, impervious, adherent scale may form on the evaporating surfaces, (*a*) one consisting largely of calcium sulphate; and (*b*) the other containing a relatively large proportion of hydrous magnesium silicate. Mixtures of these two types may form from waters containing both bicarbonate and sulphate. As a rule calcium silicate is not found, though a few scales have been examined in which it is present.

MECHANISM OF SCALE FORMATION

In order to prevent deposits of this type it is necessary to understand the mechanism by which they are laid down.

Different methods of attack on this problem have led to the conclusion that the growth of adherent scale is due to deposition *in situ*—that is, the individual crystals composing the framework of the scale

have never existed as particles free to move with the flow of the boiler water, but were deposited from saturated solution in crystalline form at the point where they are found as scale. An exception to this is the broken pieces of scale which have formed as stated, but have come loose from the evaporating surfaces and moved to some other point

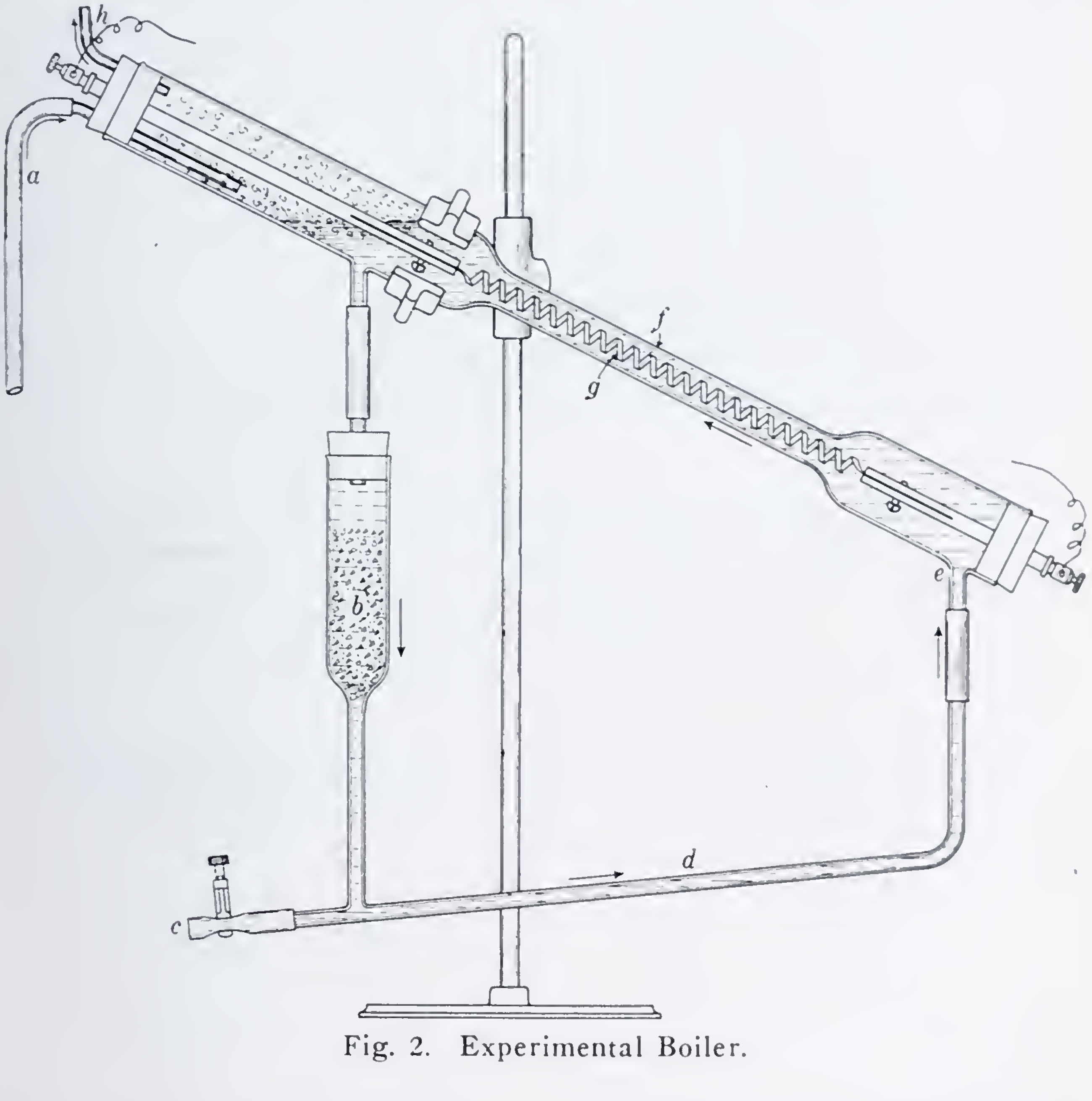

Fig. 2. Experimental Boiler.

in the boiler, where they may or may not have become cemented in with the other scale. The reasons underlying these conclusions are as follows:

1. A 42-day chemical balance* was made on a 500-horse-power Heine boiler operating at 150 to 160 pounds pressure and a rating of about 150 per cent. Analyses were made on feed-water, boiler water,

*A system of boiler-water treatment based on chemical equilibrium, by R. E. Hall. Industrial and Engineering Chemistry, 1925, v. 17, p. 283-291.

blow-down water, scales, and sludges. The amount of suspended matter in the water was also determined. During this entire period the amount of suspended matter in the boiler water varied from a maximum of 22 to a minimum of seven parts per million, and yet the balance showed that as much as 57 pounds of scale a day was being laid down on the evaporating surfaces; 89 per cent. of all calcium sulphate entering the boiler during this period was deposited as adherent scale. It was impossible for this amount of scale to be derived from the suspended matter in the water.

2. In the experimental boiler shown in Fig. 2 the "Nichrome" heating element corresponds to the evaporating surfaces in a boiler. When water containing calcium sulphate is evaporated in this boiler, very few loose crystals appear in the water, but a scale is formed over the surfaces of the "Nichrome" ribbon. Data taken with this boiler are shown in Table III. In No. 5 of this table sodium hydroxid and

TABLE III. SOLUTIONS USED IN EXPERIMENTAL BOILER IN TESTING THE DEPOSITION OF SCALE *IN SITU*

Concentration, parts per million

No.	$CaSO_4$	Na_2SO_4	NaC	NaOH	Tannic acid	$Al(OH)_3$
1	Saturated	4000	....	...	...	...
2	Saturated	....	4000	...	...	...
3	Saturated	2000	2000	...	...	...
4	Saturated	2000	2000	600	...	...
5	Saturated	4000	....	600	200	...
6	Saturated	2000	2000	200	...	210

tannic acid were present and in No. 6 sodium hydroxid and aluminum hydroxid, in order to find if the flocculent type of precipitate derived therefrom might coat the individual particles of calcium sulphate and thereby prevent scale. In every case noted in Table III, adherent scale formed on the heating element. In No. 1 to No. 4 some loose crystals were formed simultaneously. In No. 5 and No. 6 their appearance was masked by the flocculent precipitate throughout the solution in the boiler.

These results are in direct contrast to the statements of Alexander,* who says:

"Most 'boiler compounds' contain such soluble colloids as dextrin, tannin, and bark extract, and some engineers put potatoes or starch in their boilers together with soda ash.

Any precipitate formed in the presence of these colloids adsorbs them and tends to remain in a finely dispersed non-coherent condition, so that it is readily removed when the boiler is blown down. The formation of hard crystalline scale is thus prevented."

As the deposition of calcium sulphate occurred *in situ*, however, even when tannin was present, it is obviously impossible that it be removed by blow down.

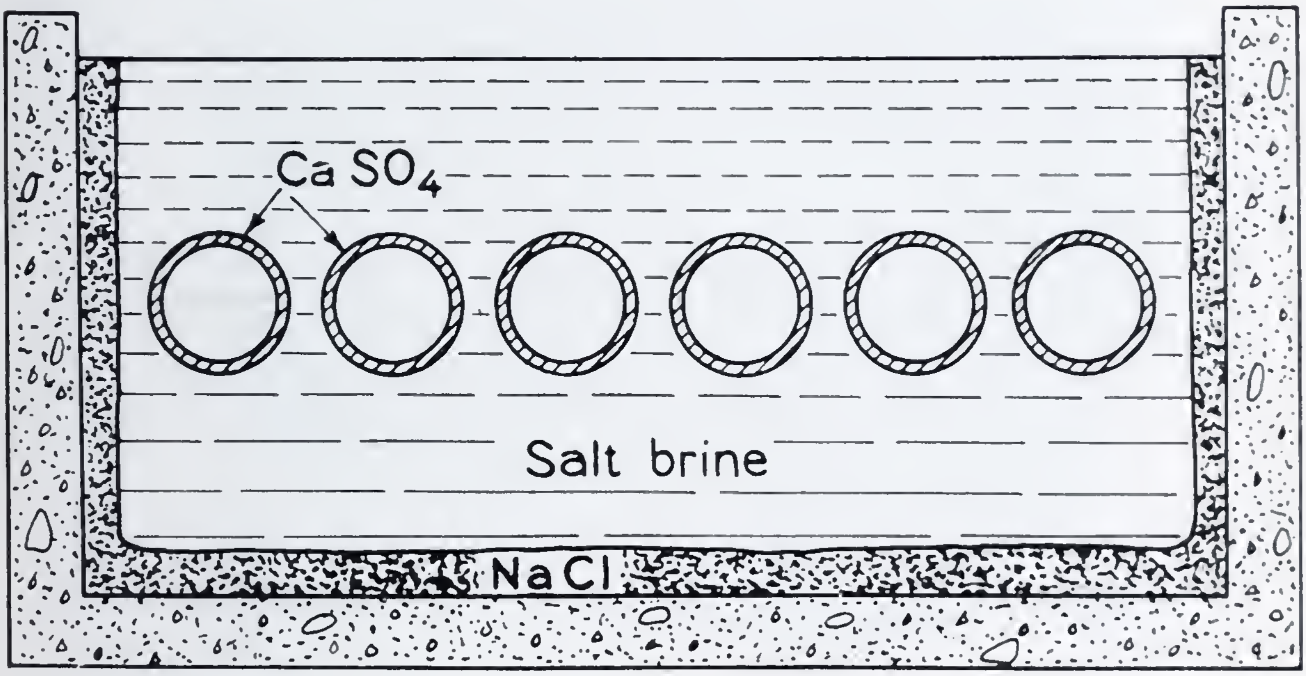

Fig. 3. Salt Grainer.

3. A study of equilibrium conditions in a salt evaporator furnished proof of this generalization.† The salt brine is evaporated in concrete grainers. These grainers comprise large, shallow, rectangular chambers fitted with tubes of large diameter with steam on the inside (Fig. 3). The steam is admitted at such a rate that no ebullition takes place. Evaporation goes on quietly with no disturbance of the liquor surface and thus provides ideal conditions for uniform deposits of scale. Salt crystals form on the surface and gradually settle to the bottom of the grainer. A dense scale forms on the steam-pipes and a

*Colloid chemistry, by Jerome Alexander, 1924. Van Nostrand, N. Y. p. 162.

†Some problems in boiler-water chemistry, by J. A. Robb. Thesis. Co-operative fellowship, U. S. Bureau of Mines and Carnegie Institute of Technology, 1924-25.

rather soft, thick scale on the sides of the grainer. This latter scale is cut off every two or three hours. The analysis of the brine (Table IV) shows it to contain considerable calcium, magnesium and sulphate, in addition to common salt. The analysis of the salt from the grainer and the scale from the steam lines show how nearly perfect a separation of the constituents in the brine may be effected because of

TABLE IV. ANALYSES OF BRINE, SALT, AND SCALES DEVELOPED IN SALT-GRAINER OPERATION

A. Brine from grainer after 35 days of operation, parts per million

SiO_2	Fe	Ca	Mg	SO_4	NaCl	Suspended matter	Dissolved solids
16	14	4650	288	1560	253,000	5.3	266,400

B. Loose salt and scale on side walls developed from brine in A, per cent.

	SiO_2	Fe	Ca	Mg	SO_4	NaCl (by difference)
Salt	0.005	0.005	0.48	0.18	0.34	99.0
Scale	0.017	0.007	0.48	0.04	0.70	98.8

C. Scale from the steam-pipes, per cent.

SiO_2	Fe_2C_3	CaO	MgO	SO_3	CO_2	Na	Cl	Loss at 105 degrees C.	Net ignition loss
0.2	1.7	35.6	0.1	48.8	0.8	3.7	5.6	1.2	2.8

differences in the form of the temperature-solubility diagrams of common salt and calcium sulphate. Thus the scale on the cool side walls and the sludge collecting on the bottom of the grainer consisted of almost pure sodium chlorid. The scale on the hot steam-pipes contained almost 85 per cent. of calcium sulphate. It is apparent at once that this scale grew directly on the pipes and is quite independent of the salt sludge which was the primary product of the grainer.

4. Fig. 4. is a thin section of calcium-sulphate scale photographed by transmitted light with slight magnification.* The ordinary banded structure of such a scale is apparent. At right angles to these bands appear long needle-like forms stretching across the bands and of marked length. These are the individual crystals of calcium sulphate, and the time which has been consumed in their growth is quite apparent from the number of bands which they stretch across. Such a formation could not be the result of other than the gradual growth of the crystal in a saturated solution with deposition occurring gradually over a period of days.

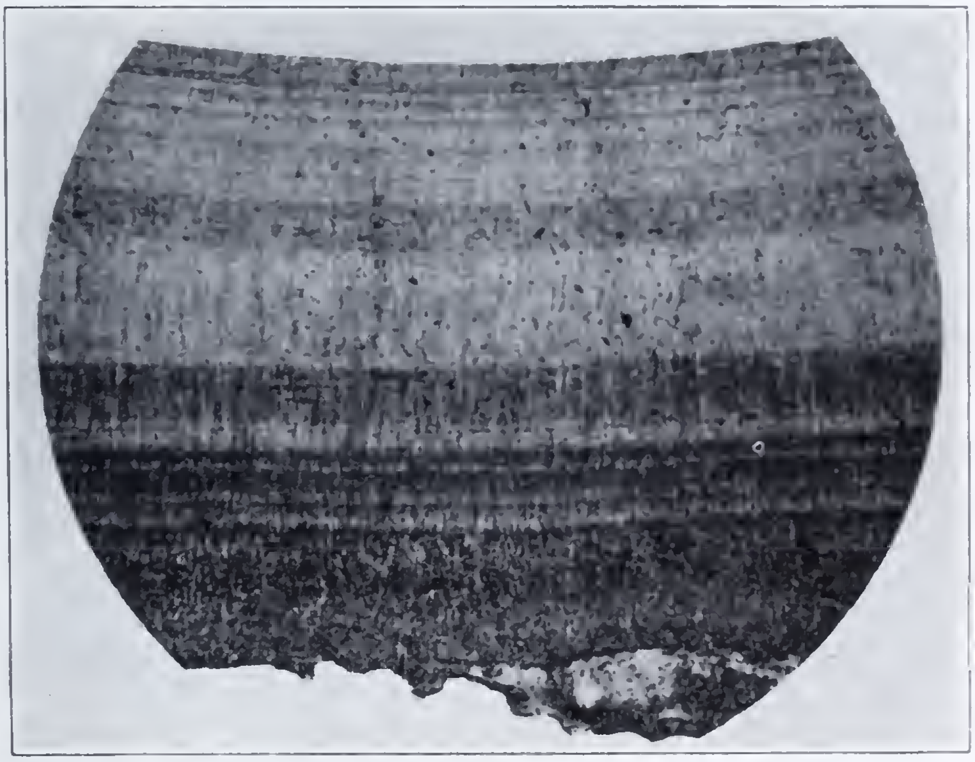

Fig. 4. Thin Section of Calcium-Sulphate Scale Showing Banded Structure, and the Growth of Long Needle-Like Crystals Normal to the Bands. × 300.

Fig. 5 is a section of relatively pure calcium-sulphate scale in which a small section of scale has lodged and then been incorporated into the main body of scale by the growth of the main scale over it. The line of demarcation between the main scale and the broken piece is perfectly distinct, and the growth of the main scale has gone on slowly and regularly, as evidenced by the bands in this scale following for many days or weeks the direction given to them by the incor-

*The writer is indebted to A. H. Emery, Assistant Geologist and Petrographer, and G. H. Henneman, Photographer, of the U. S. Bureau of Mines, for co-operation in the preparation of these photomicrographs. A paper regarding them will be published in the near future.

porated piece of loose scale. A formation of this type could not occur other than by deposition *in situ*.

Fig. 6 is a section of calcium-sulphate scale which has incorporated in it considerable loose suspended matter from the boiler water. It shows the long needle-shaped crystals of calcium sulphate projecting upward and acting as a catch-all for any suspended material which may settle among them. Once there, this suspended material is incorporated into the scale by the further growth of the

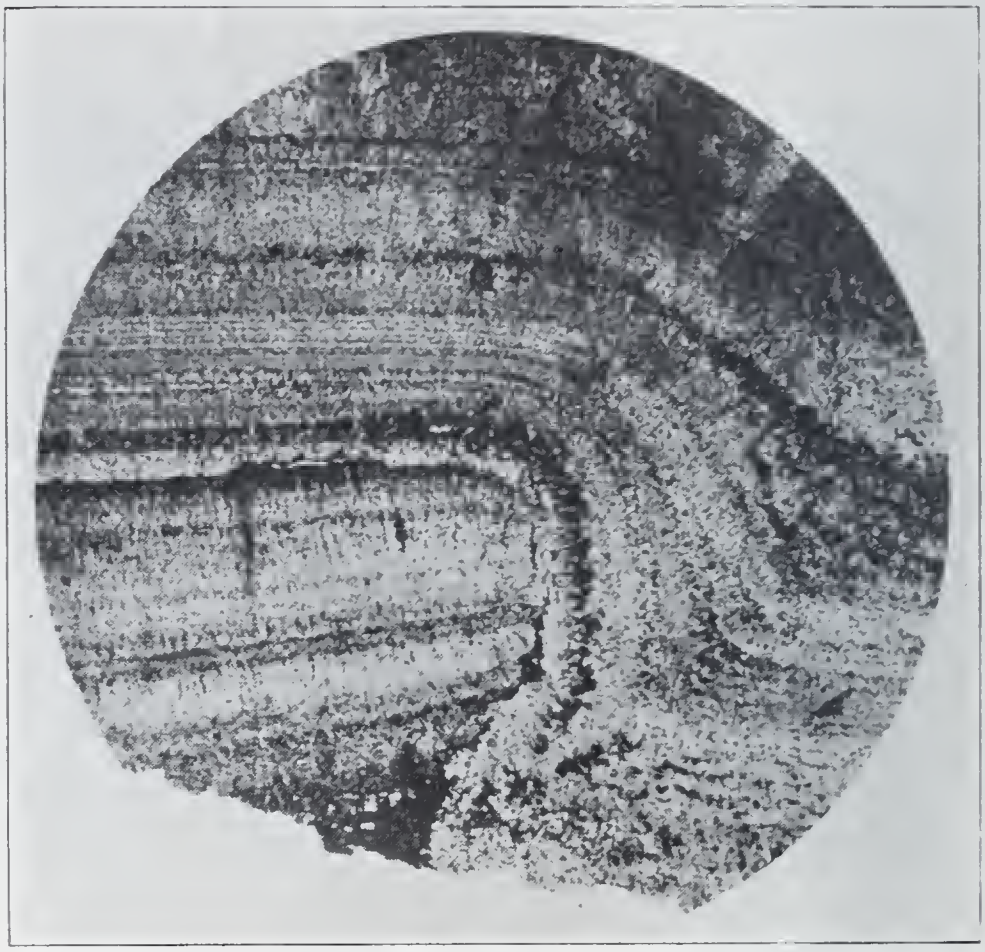

Fig. 5. Thin Section of Calcium-Sulphate Scale, Showing the Main Scale Growing Over and Incorporating into It a Broken Section of Scale.

calcium-sulphate crystals. In this way on the evaporating surfaces there may be formed an adherent scale which contains considerable calcium carbonate.

That the growth of calcium-carbonate scale in the feed lines or in the preheating sections of the boiler is no less due to deposition *in situ* is evidenced by the regular banded structure of such scales and their growth around the entire periphery of tubes and pipes.

MEANS OF OBVIATING SCALE FORMATION

So far as the evaporating surfaces are concerned, prevention of scale formation means the prevention of the formation of calcium sulphate and hydrous magnesium silicate. Where it is feasible, the most economical method of doing this is by so controlling the boiler water that calcium carbonate and magnesium hydroxid will precipitate at all times in preference to calcium sulphate or hydrous magnesium silicate. This can be done by treating with an amount of soda-ash

Fig. 6. Thin Section of Scale, with Framework of Calcium Sulphate, and with Suspended Material Entrapped in the Interstices.

which is dependent upon the sulphate concentration of the boiler water and the operating pressure of the boiler. Thus at 125 pounds gage pressure (Fig. 7), when the sulphate concentration is 1000 parts per million, the amount of carbonate (CO_3 radical) which must be present in the boiler water is 65 parts per million, or slightly more; but, if the sulphate concentration is 2000 parts per million, then the amount of carbonate radical must be slightly above 130 parts per million. On the other hand, if the operating pressure of a boiler is

200 pounds, then for a concentration of 1000 parts of sulphate the carbonate radical must be 145 parts per million, or more, and for 2000 parts of sulphate the carbonate radical must be 280 parts per million, or more. If these conditions are regularly maintained, adherent scale will not form on the evaporating surfaces.

Soda-ash, however, at boiler-water temperatures, and especially at higher ratings, is not a stable chemical. It reacts with the water to form caustic soda, and carbon dioxid gas (CO_2) is liberated in the steam. Therefore, at higher operating pressures, and at medium

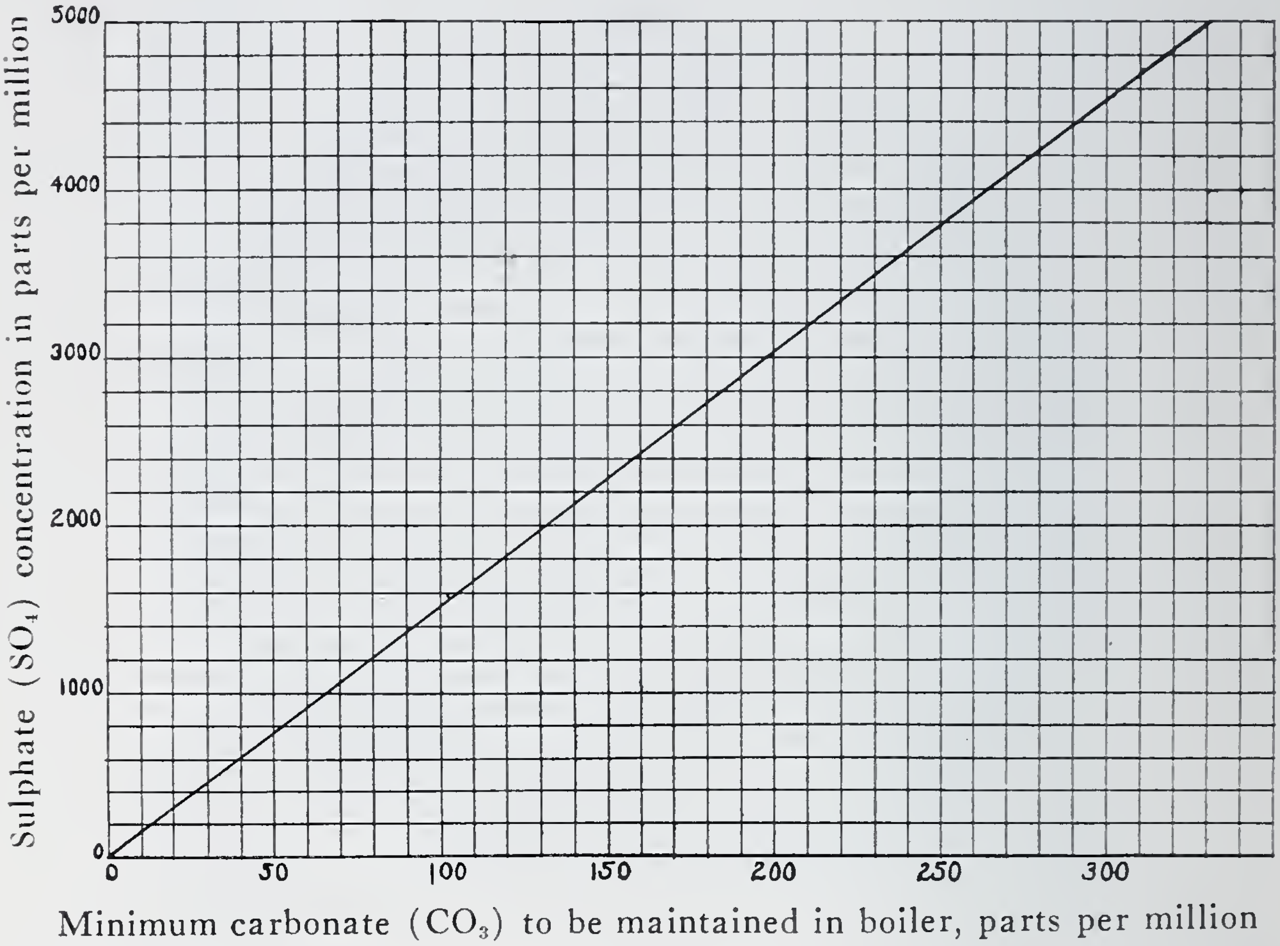

Fig. 7. Relation of Sulphate to Carbonate for a Boiler Operating at 125 Pounds Gage Pressure.

operating pressures at high ratings, it becomes impossible to maintain sufficient carbonate radical in the water to meet conditions such as those just described. That this is the case is well illustrated by the conditions found in a Bigelow-Hornsby boiler in which the make-up water was practically 100 per cent.*

As seen from Table V, the feed-water was treated with lime and soda-ash and the boiler water was high in sulphate content. The

*Some problems in boiler-water chemistry, by J. A. Robb. Thesis. Co-operative fellowship, U. S. Bureau of Mines and Carnegie Institute of Technology, 1924-25.

TABLE V. WATER, SLUDGE, AND SCALE FROM BIGELOW-HORNSBY BOILER

Water, parts per million

Sample	Total solids	Suspended solids	SiO_2	Fe	Ca	Mg	Na	OH	CO_3	HCO_3	SO_4	Cl
Feed water, external treatment with lime and soda-ash	236	24	6	3	15	2	55	0	38	4	73	15
Boiler water, taken from element *b* at gage glass	11 500	347	13	15	32	1	3840	95	324	0	5500	1360

SLUDGE AND SCALE, PER CENT.

Sample	SiO_2	Fe_2O_3	CaO	MgO	SO_3	CO_2	Loss at 105 degrees C.	Net ignition loss
Sludge from *b* and *c* elements	11.7	8.1	25.8	20.9	6.0	16.7	0.7	11.6
Scale from *b* element	2.5	3.2	50.0	3.7	1.8	37.6	0.2	1.5
Scale from *a* element	0.8	0.5	40.4	1.5	53.3	0.6	0.3	0.9

sludge from the rear elements, *b* and *c*, Fig. 8, contained a considerable amount of calcium carbonate, magnesium hydroxid, and magnesium silicate. The thin, porous scale from element *b* was almost practically pure calcium carbonate, but the evaporating surfaces of the front element *a*, where the greatest heating of the tubes occurred, were covered with an adherent, impervious, growing scale, which was almost pure calcium sulphate. The excess carbonate carried into the

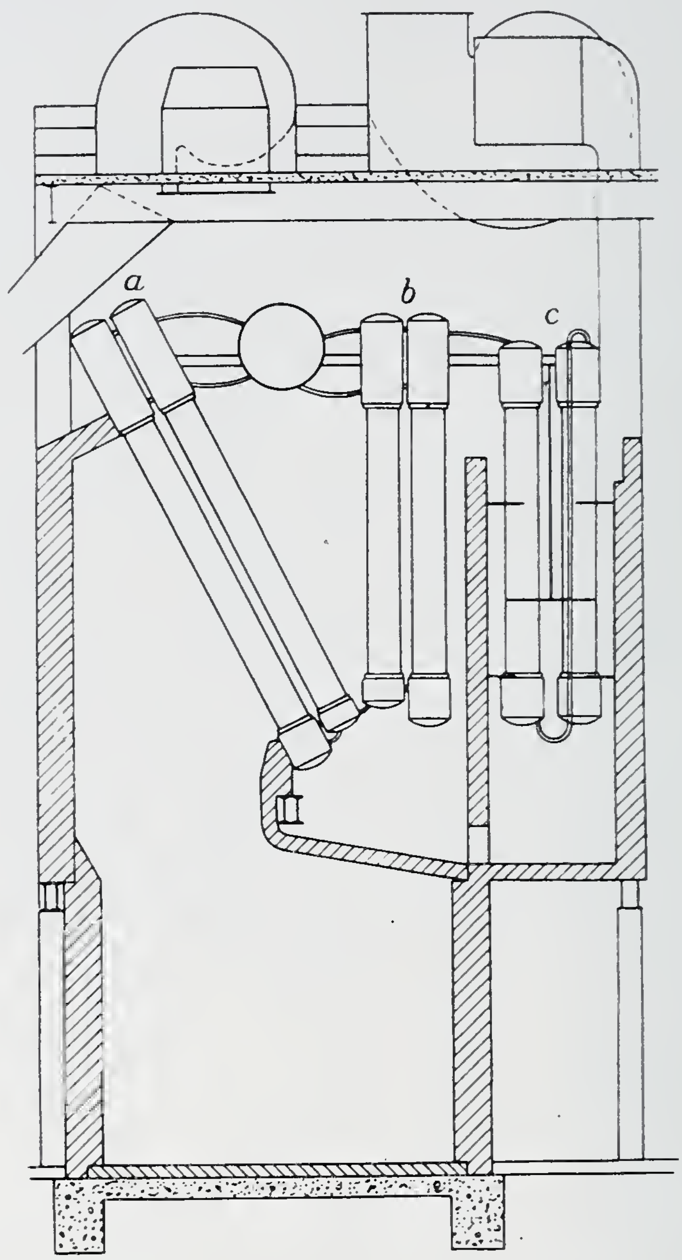

Fig. 8. Bigelow-Hornsby Boiler.

boiler was used up or decomposed in the rear elements; in the front element, accordingly, ideal conditions existed for the deposition of calcium-sulphate scale. Therefore, where the use of soda-ash becomes infeasible because of its decomposition, it is necessary to turn to a chemical which is stable under these conditions. Sodium phosphate answers the requirements and the solubility of calcium phosphate—

not more than ten parts per million at boiler-water temperatures—is so small that the deposition of calcium sulphate can be entirely inhibited regardless of the pressure of operation. The validity of these conclusions has been demonstrated recently in reports made to the Prime Movers Committee of the National Electric Light Association. See Serial Report of the Prime Movers Committee, Publication No. 25-68, 1925, p. 8-10.

We may summarize the inhibition of scale formation on the evaporating surfaces in a sentence: Maintain conditions in the boiler water such that the solid calcium salts in equilibrium are the phosphate or carbonate, and the solid magnesium salts are the phosphate or hydroxid.

On the surfaces of the pipe-lines from the feed-water heater to the boiler, or the surfaces of the preheating sections where evaporation does not occur, calcium carbonate may be deposited as an adherent scale. In order to prevent this formation it is necessary that no bicarbonate radical remain in the water, and it is advisable that loose crystals of suspended calcium carbonate be present. If the water has been treated externally, and sufficient time given for complete reactions to occur, no trouble should be experienced from this type of scale. If, however, this is not the case, satisfactory conditions can be brought about by passing a portion of the boiler water through an external filter. This filter removes all the larger crystals of the sludge, but allows the hydroxid developed in the boiler and the smaller crystals of sludge to pass. The effluent water from the filter may then be introduced into the feed lines or the preheating sections of a boiler where the hydroxid will neutralize any bicarbonate present, and the small crystals of calcium carbonate will serve as nuclei for the precipitation of the dissolved calcium carbonate.

CORROSION FROM THE EVAPORATION OF NATURAL WATERS, AND POSSIBLE METHODS OF PREVENTION

We shall turn now to the question of corrosion. Fig. 9 shows the corrosion of a nipple close to the boiler in the feed-water inlet line. This specimen is from a boiler operating in Rhode Island. The feedwater was very pure except for its dissolved oxygen and carbon dioxid.

Fig. 10 illustrates corrosion in steam economizers. In this case

Fig. 9. Corrosion of a Nipple Close to the Boiler in the Feed-Water Inlet Line.

New York City water, containing some bicarbonate radical and dissolved oxygen, was used.

Fig. 11 shows corrosion in a tube in the preheating sections of a Bigelow-Hornsby boiler. This pit occurred just above where the tube was expanded into the lower drum. This occurred in a Massachusetts plant which uses one of the bicarbonate waters characteristic of the Eastern coast.

Fig. 12 shows corrosion going on in a tube under sulphate scale developed by evaporation of Monongahela River water.

Fig. 13 shows corrosion in the boiler drum under sulphate scale developed by evaporation of this same water. Under every one of the bubbles seen in the scale a pit was developing.

The present-day theory of corrosion places the responsibility for corrosion such as illustrated upon (1) the presence of dissolved oxygen

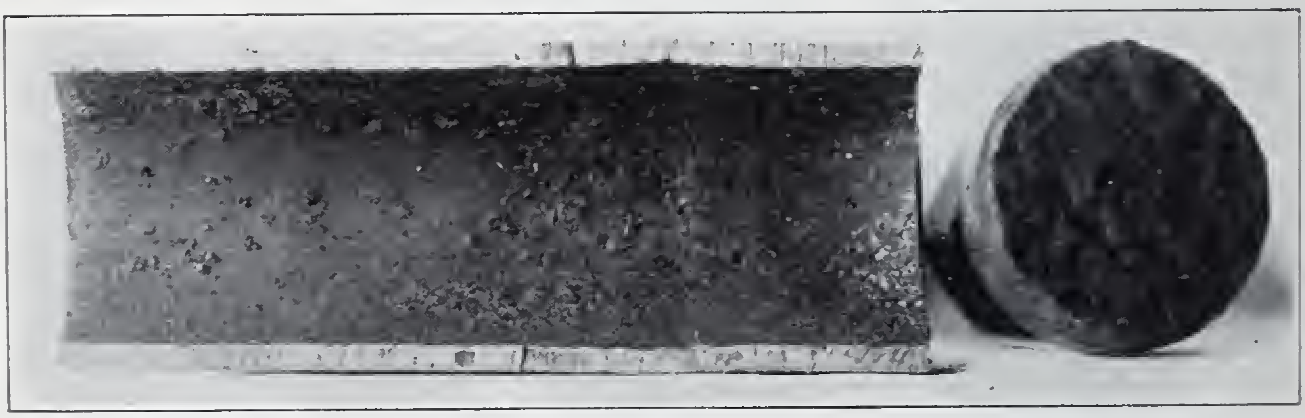

Fig. 10. Corrosion of Steam Economizer by New York City Water.

Fig. 11. Corrosion in a Tube in the Preheating Element of a Bigelow-Hornsby Boiler.

in the water; (2) an unsatisfactory hydrogen ion concentration, developed usually by dissolved carbon dioxid; and (3) differences of potential developed in various ways. Presumably all the types of corrosion illustrated are electrochemical in character.

Fig. 12. Corrosion in a Tube under Sulphate Scale.

Two methods seem available for inhibiting the type of corrosion depicted in the preheating sections of the boiler:

1. The de-aëration of the water—by the maintenance of sufficiently high temperatures and excellent venting in the feed-water heater, or by the use of de-aërators—will remove a large proportion of dissolved oxygen. When a water contains bicarbonate radical, however, these means, by themselves, are insufficient for its satisfactory removal.

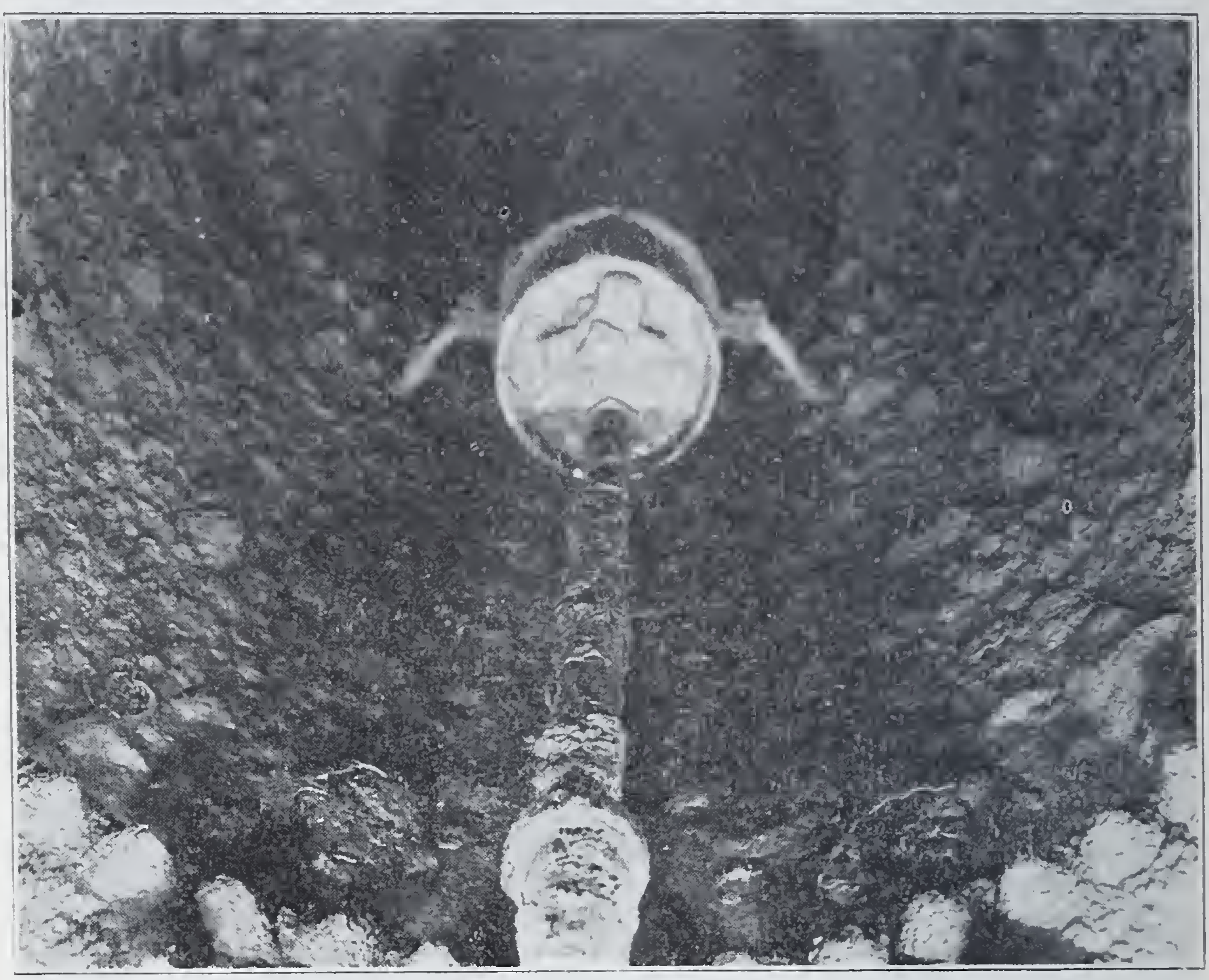

Fig. 13. Corrosion in Boiler Drum under Sulphate Scale.

2. This type of corrosion may be controlled by the use of caustic or other suitable chemical. At the present time, under the co-operative agreement between Carnegie Institute of Technology and the United States Bureau of Mines, work is proceeding on the maintenance of this type of control.

When soda-ash or sodium phosphate is used for conditioning the boiler water, enough caustic is developed by the decomposition of carbonate radical or the hydrolysis of the phosphate to inhibit corro-

sion satisfactorily on the evaporating surfaces as shown in Fig. 14. In this illustration, two points are of especial interest:

1. In Fig. 13 the time of exposure necessary to obtain a picture of the dirty, red-colored scale which had formed was four minutes; in Fig. 14 the exposure was for only one minute, as the white coating of carbonate was a very much better reflector of light.

2. Whereas in Fig. 13 there are innumerable excrescences, convex outward, with a pit under each, in Fig. 14 the thin carbonate

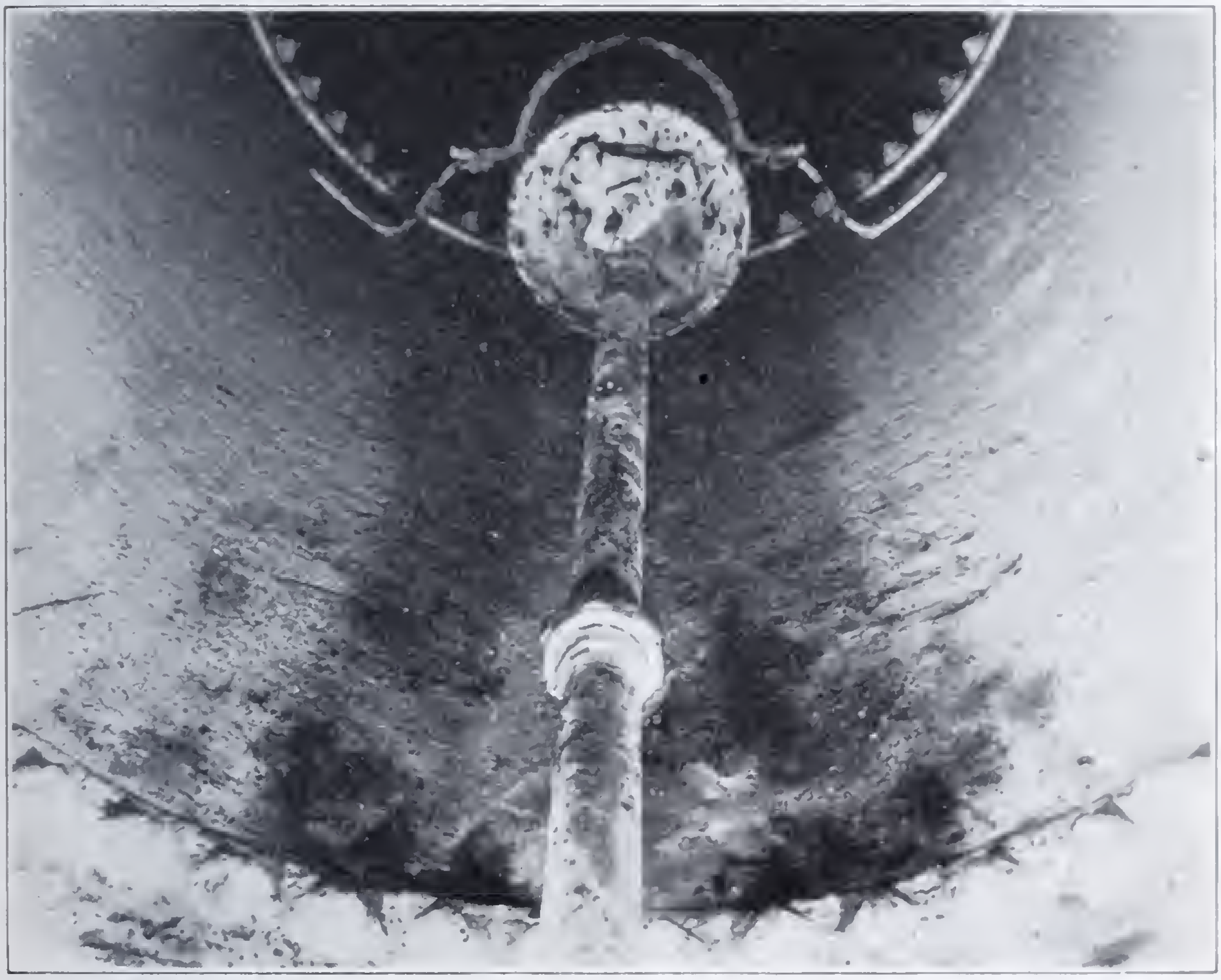

Fig. 14. Effect of Hydroxid in Inhibiting Corrosion.

coating follows accurately the outlines of the pit, showing that further action has been inhibited.

BOILER-WATER SLUDGES AND STEAM-LINE DEPOSITS

In Table VI, section A presents analyses of sludges in the boiler water and deposits from the steam lines when treatment has been made either with soda-ash internally or lime and soda-ash externally.

TABLE VI. ANALYSES OF SLUDGES AND STEAM-LINE DEPOSITS, PER CENT.

A. Treatment with soda-ash, or lime and soda-ash

No.	Treatment of water	Type of deposit	SiO_2	Al_2O_3 + Fe_2O_3	CaO	MgO	SO_3	CO_2	Loss at 105 deg. C.	Net ignition loss
1	Internal with soda-ash	Sludge from filter attached to boiler	6.1	4.3	39.1	9.0	0.7	30.4	0.3	9.9
2	Internal with soda-ash	Sludge from filter attached to boiler	28.5	18.2	8.0	11.4	2.5	4.8	2.1	24.9
3	Internal with soda-ash	Sludge from filter attached to boiler	5.9	10.2	33.4	11.0	1.7	25.6	0.4	12.9
4	External, lime and soda-ash, filtered	Deposit from superheater headers	10.6	6.3	18.9	26.4	6.6	14.4	1.1	14.6
5	External, lime and soda-ash, filtered	Steam-trap deposit, 400 feet from boiler house	12.5	7.8	19.2	28.0	2.0	14.7	2.0	15.3
6	Internal with soda-ash	Steam-trap deposit	5.4	7.2	37.6	10.6	1.2	28.6	0.5	10.2

Boiler characteristics

No.	Type	Horse-power	Pressure	Rating
1	Heine	545	160	150
2	Erie City	580	150	100
3	Stirling	250	150	125
4	Babcock & Wilcox	400	160	125
5	Babcock & Wilcox	400	160	125
6	Heine	545	160	150

B[a]. Internal treatment by sodium phosphate

Type of boiler; Babcock & Wilcox. Operating pressure; 325 pounds per square inch. Type of treatment; sodium phosphate, internal

Source of sample	Date	SiO_2	Fe_2O_3	CaO	MgO	Na_2O	SO_3	CO_2	P_2O_5	Moisture at 105 degrees C.
No. 12 boiler drum	7/ 9/25	7.3	35.8	17.4	2.4	2.4	0.6	7.0	28.1	....
No. 10 superheater header	6/30/25	21.1	25.6	16.5	6.4	1.5	1.2	1.3	26.3	....
No. 12 superheater tube	6/22/25	16.0	28.6	18.4	5.3	3.5	1.5	3.5	23.2	....
No. 4 unit first row impulse blades	7/14/25	17.6	20.8	12.0	2.8	4.2	2.0	3.7	18.8	18.1[b]

a The writer is indebted to L. E. Hankison of the West Penn Power Co. for calling these data to his attention, and giving permission to use them. Analyses by M. D. Baker, West Penn Power Co.

b Moisture in sample from No. 4 unit undoubtedly absorbed after sample was collected.

The first point to note is the very small amount of SO_3 (this signifies calcium sulphate when combined with lime) in these deposits. This shows that conditions have been correct at practically all times to eliminate any formation of solid calcium sulphate in the boiler water.

A point of great significance, too, is the high percentage of MgO in the steam-line deposits, in general. Calcium-carbonate crystals are of relatively large size when compared to those of magnesium hydroxid, which has more of the characteristics of a flocculent precipitate similar to that obtained by the use of alum as a flocculating agent in water softening. It is characteristic, therefore, that the material which has been entrained in the steam should consist in a greater percentage of this finely divided flocculent precipitate than of the larger calcium-carbonate crystals.

In section B of Table VI are given the analyses of the deposits appearing as sludge in the boiler drum and as a powder in the superheater header, superheater tube, and on the first row of impulse blades of the turbine when internal treatment of the water by sodium phosphate has been the practice. Calcium phosphate, like magnesium hydroxid, is a flocculent precipitate and is present in large proportion in all deposits of this section. It is evident from a study of the table that the amount of calcium carbonate remaining in the sludge was of greater percentage than that which was entrained in the steam and appeared in the steam-line deposits.

CONTROL OF SUSPENDED MATERIAL AND WET STEAM

The control of the amount of suspended material which shall be present in the boiler water is entirely a mechanical problem. With the use of a lime and soda-ash external treatment the water will go to the boiler containing for every million pounds of water from 25 to 40 pounds of material which will develop into sludge, which depends upon the completeness of the reactions and efficiency of filtration. With a base-exchange process working properly, the quantity of suspended material which will develop in the boiler water should be less. While the total of suspended material developed in the boiler water over any period will be greater if treatment be applied directly without external filtration, the amount present at any moment may be

controlled definitely by continuous filtration of a part of the boiler water. As regards control of sludge, the latter method amounts to a continuous blow down equal to the amount of water filtered, but represents negligible heat loss because the water is returned to the boiler at almost the same temperature at which it was withdrawn. The latter method is the most flexible of all, whether applied to a water treated externally or to one treated directly in the boiler, because it places in the hands of the boiler operator complete control of the quantity of suspended material in the water, since he can regulate at will the amount of water passing through the filter.

The quantity of soluble material left in the boiler water will be least when full barium treatment is applied. It is the same for external lime and soda-ash treatment or for internal treatment with soda-ash or sodium phosphate. The solubles left in the boiler water will be greatest in the case of the base-exchange treatment, excepting for a water entirely devoid of bicarbonates.

What is the relation of the content of soluble and suspended material in the boiler water to the percentage of moisture in the steam? Table VI shows that the deposits in the steam lines represent faithfully the composition of sludges in the boiler water; and in section B, especially, contain sodium compounds which result from the evaporation of some of the boiler water. The experimental work of Foulk* has given a fair idea of what happens with different concentrations of these factors up to pressures of approximately 50 pounds. He says:

"In the case of the sodium salts which were studied in some detail, a fair amount of foam was obtained with concentrations of 1000 p.p.m. if the amount of insoluble material was sufficient. Foaming increased with increasing concentration of the soluble material till about 7000 p.p.m. were reached. After that there was no change.

Increasing the amount of insoluble material had the same effect as an increase in the concentration of the soluble solids. One of them, therefore, could take the place of the other so that foams could be produced with a small amount of soluble material provided a large amount of insoluble solid was present, and vice versa. There was, however, a lower limit at about 500 p.p.m. for both soluble and insoluble material—that is to say if the soluble salts were much less than this no reasonable amount of insoluble material would produce foam, and if less than this amount of insoluble matter was present no concentration of soluble salts was sufficient to make the liquid foam."

*Foaming of boiler water, by C. W. Foulk. Industrial and Engineering Chemistry, 1924, v. 16, p. 1121-1125.

Without any indications of foaming, however, the steam may carry a high percentage of moisture and, therefore, of entrained solids. This is especially true when the boiler is driven at high rating and when, therefore, the level of the water indicated by the gage-glass may be least truly indicative of the level of water in different parts of the steam-drum. It seems advisable, therefore, in every case to protect the steam lines from the boiler water and the suspended material therein by mechanical arrangements which will insure the separation of these more dense materials from the steam, and deliver the steam so that any condensate resulting therefrom will be free of both suspended and soluble material.

CONTROL OF NON-CONDENSABLE GASES IN THE STEAM

One other factor remains to be discussed. What non-condensable gases are present in the steam and what is their relation to the type of treatment used? This is a point of great importance where the steam is to be used for process work or for heating purposes. In the latter, condensation occurs in lines far removed from the boiler, and if the non-condensable gases can cause corrosion, trouble will arise in time. This problem has been investigated during the past year under the co-operative fellowship agreement* existing between the United States Bureau of Mines and the Carnegie Institute of Technology. In this work it has been shown (1) that part of the oxygen which enters in the feed-water persists in the steam; (2) that considerable hydrogen is produced in the boiler by the interaction of the heated water and the metal of the boiler and is carried in the steam; (3) that the carbon dioxid resulting from the decomposition of soda-ash used in treatment is carried in the steam and may represent at times more than 95 per cent. of the non-condensable gases in the steam.

Table VII shows the rate of conversion of sodium carbonate over a period of hours and at different ratings and pressures.

The presence of carbon dioxid and oxygen in the steam should be limited to the least possible amount wherever any condensate from the steam is to be in contact with metal surfaces for any period, because they are readily soluble in water and are corrosive. Means

*The carbon dioxide and oxygen chemistry of some boiler waters, by H. S. Karch. Thesis. Co-operative fellowship, U. S. Bureau of Mines and Carnegie Institute of Technology, 1924-25.

TABLE VII. RATE OF DECOMPOSITION OF SODIUM CARBONATE

Date	Average rate condensate per hour, liters.	Temperature, degrees C.	Initial CO_3 conc., p.p.m.	Rate of conversion of Na_2CO_3 in per cent. per hour, hours.									
				1	2	3	4	5	6	7	8	9	10
3/30/25	0.34	129	486	5.2	6.2	6.4	6.4	5.8	5.6	5.2	5.0	...	...
3/31/25	0.55	143	483	11.2	10.6	9.0	6.8	5.8	5.6	5.4	5.4	...	...
3/ 4/25	0.20	145	383	15.4	15.4	12.4	6.4	5.0	3.8	3.0	2.2	1.8	1.4
3/ 5/25	0.10	158	456	8.4	8.0	8.0	8.0	7.4	5.8	3.2	1.6	0.6	0.2
4/ 1/25	0.49	158	533	11.8	11.8	10.8	8.4	5.4	3.8	3.4	3.0	2.8	...
3/ 9/25	0.35	168	495	22.2	14.2	9.6	6.0	4.0	3.2	2.8	2.6	2.2	1.8
3/12/25	0.83	176	530	15.4	15.4	15.4	13.4	2.8	...	...	...	...	...
3/11/25	0.10	177	545	11.8	8.8	6.6	5.8	5.2	4.6	4.2	3.8	3.6	3.6
4/ 8/25	0.25	185	1134	10.6	8.4	6.0	4.8	4.4	4.0	3.6	3.2	...	...
4/16/25													
Sugar present	0.41	183	440	16.7	15.0	13.2	10.9	7.5	3.7	2.4	1.0	...	...
2/26/25	0.59	183	456	28.6	16.6	12.4	9.0	7.4	6.4	...	...	...	...
3/16/25	1.89	185	545	21.0	14.8	11.4	8.8	5.6	2.8	1.6	...	...	...
3/17/25	1.06	188	530	28.6	25.0	15.4	8.6	3.4	0.8	...	...	...	...
3/18/25	0.67	198	548	....	16.6	14.2	12.6	8.6	6.8	6.4	...	...	...

have been discussed for limiting the amount of oxygen. Where it is essential to limit the amount of carbon dioxid to the least possible percentage in the steam, it becomes necessary to condition the boiler water by the use of a chemical such as sodium phosphate, which will not decompose and will therefore prevent large excesses of non-condensable gases from contaminating the steam.

SUMMARY

1. It has been shown that water softening comprises but a small part of the process of boiler-water conditioning.

2. The types of deposits that may develop from natural waters and the point in the boiler system at which they will develop have been pointed out.

3. It has been shown that the control for boiler-water conditioning must be placed on the boiler water, whatever the type of treatment used.

4. The similarity of boiler-water sludges and steam-line deposits has been demonstrated.

5. The relation of soluble and suspended material in the boiler water to the percentage of moisture in the steam has been discussed.

6. Different methods of control of suspended material in the boiler water have been described.

7. It has been shown that a suitable control of the non-condensable gases in the steam is necessary.

In conclusion, it is a pleasure to acknowledge the great assistance in this work that has been rendered by A. C. Fieldner, Chief Chemist, and other associates of the writer in the United States Bureau of Mines, and by J. M. Hopwood, president of the Hagan Corporation, and the members of his staff.

DISCUSSION

Mr. W. L. Piening:* I have some boilers in Richwood, W. Va.—54 of them, all told. I went down there in May and they were all inspected when the streams were at normal stage. I did not find any scale whatsoever. There are five big Bigelow-Hornsby boilers, 15 horizontal tubular, 18 locomotive and Harrisburg water-tube and some Keeler water-tube boilers. At that time I did not find in those boilers any scale as big as the head of a pin.

A couple of weeks ago I went down there and the streams were very low because of very dry weather all summer. I presume they had been pumping all sorts of sludge and possibly a little mud into the boilers, and in some of them, the sawmills especially, the tubes were covered just a little bit with a kind of gummy scale. What I can not understand is that when the stream is at a normal stage no scale whatsoever forms in the boilers. There must be some impurities in that water. Right there would be a good place to do a little experimenting.

Mr. R. E. Hall: I suspect that you have a bicarbonate water there. Is it mountain water?

Mr. W. L. Piening: Yes, sir.

Mr. R. E. Hall: Virtually all such waters are high in bicarbonate. What is the operating pressure of your boilers?

Mr. W. L. Piening: The Bigelow-Hornsby boilers operate at 150 pounds (allowed 167). The rest of them operate at 110 and 115, and the locomotives at 180 (allowed 200).

Mr. R. E. Hall: We must guess pretty largely as to reasons for no scale formation, unless we know the composition of the water. It is probable, however, that the waters mentioned are low in sulphate and high in bicarbonate.

*Inspector, Engineering and Inspection Division, New York Indemnity Co., Pittsburgh.

MR. W. L. PIENING: They will gladly send samples and have you make an analysis.

I have boilers which have been operating for I would say seventeen years and they are just as clean as the day they were installed.

MR. J. B. CRANE:* Have you found that the velocity of the water in the preheater and economizer makes any difference in the corrosion?

MR. R. E. HALL: Some of the work done by Whitman at Massachusetts Institute of Technology† indicates that the velocity of flow has a large influence in two ways: (1) It tends to decrease corrosion by decreasing the rate of hydrogen gas evolution; (2) it tends to increase corrosion by oxygen depolarization, by making thinner the film through which oxygen must diffuse. The former is the major effect at low velocities, and the latter at high velocities. I know of no data on preheaters and economizers; but, if sufficient hydroxid is present in the water to render the metal surface passive, corrosion is largely inhibited. The amount of hydroxid necessary, and the results attained, will depend mainly on the concentrations of sulphate and chlorid in the water.

MR. J. B. CRANE: Mr. Pons, who is engineer for Delaunay-Belleville, France, has been over here and he says experiments conducted there show that with a velocity of 1½ feet a minute they get no corrosion in their preheaters without de-aëration.

MR. R. E. HALL: I do not believe such a velocity *per se* is sufficient to inhibit corrosion markedly. It may have an effect in maintaining uniform distribution of dissolved oxygen, thereby limiting the possibilities of corrosion.‡ We should know also the hydroxyl concentration in contact with the surfaces.

MR. WILLIAM H. WALTER:§ I should like the speaker's opinion relative to a 1000-horse-power boiler operating in Philadelphia at

*Vice-President, George T. Ladd Co., Pittsburgh.
†Industrial and Engineering Chemistry, 1923, v. 15, p. 672-676.
‡Corrosion of metals, by U. R. Evans. 1924. Arnold, London. p. 72-83.
§Mechanical Engineering Department, American Bridge Co., Pencoyd, Pa.

an average of 160 per cent. of rating and 125 pounds pressure. Water fed to the boiler is from the Schuylkill River and is treated by a cold intermittent lime-soda process. An effort has been made to treat the boiler water with sodium carbonate in such amount as is required by the determined sulphate concentration. The more sodium carbonate that was pumped into the boiler the less carbonates and the more hydroxids were determined. The conclusion was reached that the sodium carbonate was decomposing. Treatment with trisodium phosphates was then attempted, and this treatment has been in use for the past month. Although charging into the boiler 90 pounds a day of trisodium phosphate we have never been able to detect more than four to five parts per million in the water. By the time treatment is brought up to the amount required by the determined sulphate concentration (unless excessive blowing down is resorted to) the condition of foaming and priming will make itself manifest.

MR. G. W. SMITH:* In the time that we have been applying the principles of water treatment developed at the United States Bureau of Mines we have met with nearly every known type of feedwater treating equipment. The result of our experience is that we have no quarrel with any specific type of apparatus, provided it may be used in bringing the water in boilers to those conditions we desire to maintain. For example, we consider a lime-soda softener an excellent mechanical tool for measuring and storing water, for dispensing and mixing chemicals with the water, and for removing a portion of the reaction products. Since, however, we know that the ultimate criterion of scale and corrosion prevention is the condition of the water at the point of use, and not the condition of the water before concentration, we feel that no amount of effort to produce a "standard" water will in all cases and at all pressures prevent the formation of scale or the progress of corrosion. I have in mind two or three cases which illustrate this point.

In one case a large, well operated and well maintained lime-soda softener produced water for make-up purposes which resulted in no scale deposition for some time. Condenser leakage then developed in increasing amounts, and, even though the boilers were still fed with

*Supervising Chemical Engineer, Hagan Corporation, Pittsburgh.

"standard" water from the softener, scale was deposited and the troubles associated with scale were experienced. Recommendations were made that a small amount of secondary treatment (in this case soda-ash) be added with the remaining soda-ash in the softener. The amount of the secondary treatment was regulated according to the conditions made known by tests of boiler water. The scale was prevented and excellent operating conditions maintained, but a "standard" water was no longer used.

In another case "standard" water was used as 30 per cent. make-up in several Stirling type boilers. The condensate was from reciprocating engines and contained considerable oil. Under these conditions a very small amount of scale may have been deposited, but the oil accumulated in clots in the steam drums, and particularly in the upper bends of the last rows of tubes in the front bank, causing tube failures and requiring the frequent replacement of entire rows of tubes. By proper secondary treatment we insured that the residual hardness in the 30 per cent. make-up was all precipitated as sludge. This amount of sludge proved sufficient to absorb the oil, enabling the oil to be removed with the sludge by filtration of the boiler water.

In a third case a carefully softened water when evaporated in stationary boilers caused no corrosion, but when evaporated in locomotive boilers permitted corrosion to proceed. The remedy in this case was found to be the substitution of a different type of tube ferrules. This last instance is cited to support our contention that water treatment by no means properly ends when the water is delivered to the boiler.

Methods for the prevention of economizer corrosion, involving the maintenance of a sufficient hydroxyl ion concentration in the feed-water without too greatly increasing the boiler concentration (mentioned in Mr. Hall's paper) are now in practice.

The point which I wish to make is that almost all undesirable operating conditions, due to the water used, can be corrected, using at least partly the tools and equipment immediately at hand. To do this, however, it is necessary:

1. To have a correct conception of what does and may occur in boilers, feed piping, water-softeners, steam piping, etc., with feed-water of different types.

2. To have an intimate and comprehensive knowledge of all the operating conditions in a specific plant as they may be so affected.

3. To recognize the true function of equipment commonly employed in the treatment of feed-water and to distinguish sharply between what this available equipment will do and what it will not do.

Mr. W. L. Piening: With most of the boilers and equipment around the Pittsburgh district, sulphuric acid will attack brass and copper fittings. The only other place I have found the same condition is in a salt works in Hutchinson, Kansas. In the other 25 or 26 states in which I have inspected boilers I have never found any condition that would affect brass or copper.

Mr. O. A. Ellwood:* The recent development in connection with boiler feed for high-pressure boilers has all been towards the standardization of water with equipment and methods applicable before the water becomes boiler feed. This procedure includes more than any ordinary definition for water softening.

Boilers for the higher ratings and pressures are now supplied with what is essentially pure distilled water from which the corrosive and non-condensable gases are removed to the lowest practicable degree.

Dr. Hall in his discussion has laid great emphasis on the control of precipitation and concentration within the boiler. At this late day it is rather surprising to find so much emphasis being placed on such a method for overcoming the impurities encountered in water-supplies. This procedure, regardless of the technicalities introduced, is just what has for years been attempted through the medium of a large number of mixtures of various reagents sold under various trade names or as "boiler compounds." Most of them are based on such reagents as sodium carbonate, sodium hydroxid, sodium phosphate, sodium silicate and sodium tannate.

While it is perfectly feasible to apply reagents to modify the precipitates formed within the boiler, the problem then is to prevent their accumulation; also the accumulation of soluble impurities. The application of a filter as an auxiliary to the boiler for the removal of

*Chemical Engineer, Wm. B. Scaife & Sons Co., Oakmont, Pa.

precipitates does not render any aid in controlling the accumulation of soluble salts and only fractionally removes precipitated matter.

The maintenance of the specified ratio between carbonates and sulphates, and circulating a portion of the water through a filter, neither obviates the necessity for blowing down boilers to control the concentration of soluble substances nor brings under control operating factors not dependent upon the lime and magnesia content of the water. Water purification requires more than scale prevention to secure efficient boiler operation.

Disproving the need for conditioning water within the boiler, there are in operation a sufficient number of boiler plants supplied with purified feed-water softened and standardized to a known composition with reference to the alkalinity and calcium and magnesium content so that concentration of precipitates and soluble salts can be controlled for the prevention of adherent scale by a reasonable schedule of blow downs and water changes based on the amount of evaporation. The feed-water in these cases being a constant factor, there is no necessity for any auxiliary equipment attached to the boiler nor any supplementary treatment.

The wide variations in the total of impurities of all kinds encountered in natural waters, together with the widely varying designs of boilers, can best be met by a system of water purification that will standardize any water within accurately defined limits so that each boiler plant will then have a constant to which its particular equipment and operation can be adjusted. This applies to the prevention of deposits in heaters, feed lines and boilers, as well as to the prevention of moisture in steam, in so far as the water is responsible.

Mr. R. E. Hall: Lack of discrimination is apparent in any likening of a serious investigation of fundamental facts with the will-o'-the-wisp methods of boiler-compound use.

During the past 80 years, in the effort to produce a standardized feed-water, the processes occurring in the boiler water generated therefrom have been woefully neglected. While attention has been directed to the removal of calcium and magnesium in the feed-water, the relation to scale deposition of the carbonate-sulphate ratio in the boiler water, and of the operating pressure of the boiler, has been totally disregarded.

Three and a half years ago, when I was first assigned to this investigation, I would have seconded most heartily many of the statements made by the preceding speaker. Two years later, when some of the facts regarding the mechanism of scale formation, the necessity for maintaining a satisfactory carbonate-sulphate ratio in the boiler water, the decomposition of carbonate, and the need for phosphate at higher operating pressures and ratings had been disclosed, some of my associates at the Bureau even then considered me radical in insisting that the criterion by which to judge boiler-water conditioning was the boiler water, and not the dilute feed-water.

To-day all that is changed. It is recognized now that prevention of scale deposition is not a function of the calcium and magnesium present in the feed-water, but of the relation of carbonate or phosphate to sulphate in the boiler water. It is recognized that the value of this ratio is not a constant, but is dependent upon the pressure at which the boiler operates. If the operating pressure is high, or if the pressure is moderate and the rating is high, the rapid decomposition of carbonate in the boiler water necessitates the substitution of non-decomposable phosphate therefor. The permissible relative concentrations which must be maintained under varying operating conditions are definitely established. Even though surface condensers and evaporators ostensibly supply distilled water to the boiler, the irreducible minimum of condenser leakage has a clear path to the boiler; and its effect can be obviated only by placing control on the boiler water itself. May one believe in the self-sufficiency of a standardized feed-water with facts such as these thoroughly substantiated by theory and practical operation?

The prevention of scale formation is thus a function of controlling the composition of sludge; it does not dictate whether its deposition shall occur without or within the boiler. It is for this reason that disposal of the sludge becomes a purely mechanical proposition. Whether it shall be removed by filtration of the treated feed-water, by continuous filtration of a portion of the boiler water, by blow down, or by a combination of these methods, is a question to be decided by each engineer on the basis of the method best adapted to his needs. Regardless of the method chosen, however, the final criterion regulating its composition must be the concentration ratios in the boiler water.

The prevalence of entrained moisture in steam leaving the steam drum is common knowledge. Means for its separation are available. Each engineer must decide for himself whether he will effect such separation, or accept the risk arising from impure steam.

MR. J. B. CRANE: If you could use distilled water you would not be troubled.

MR. R. E. HALL: It is advisable under those conditions to maintain a certain amount of hydroxid concentration—50 to 100 parts per million—in the boiler water. When distilled water is used in the boiler without this precaution, any incidental leakage into the water may produce corrosive action, and, also, the direct action of the hot water on the metal is more rapid. It seems advisable, therefore, to maintain this slight reservoir of hydroxid at all times.

MR. J. B. CRANE: If you could use distilled water your only warrant for doing that would be when your make-up does not exceed a small percentage of the total water used in your boiler—say 10 per cent.; above that, the expense of evaporating water would be too great, and you have to go to some method of using chemicals to compensate for the trouble in the boiler. I wish the gentleman back there who has this cure-all for all waters would come to my office to-morrow. I have a proposition I would like to put up to him.

MR. L. J. REED:* To what extent has the speaker encountered trouble with priming and foaming in an attempt to maintain the carbonate-sulphate relation that should control scale formation? Where you have that condition what can be done to relieve it besides increasing blow down? If you have to go to increased blow down, what percentage of blow down is ordinarily necessary in order to control that condition?

MR. R. E. HALL: I would like to put that answer up to Mr. Smith. On the operating side of things I depend on him, always.

*Efficiency Engineer, Clairton By-Products Works, Carnegie Steel Co., Clairton, Pa.

Mr. G. W. Smith: There are two phenomena often inextricably confused under the general head of "foaming." The first of these is violent fluctuation of water-level made manifest in the gage-glass of a boiler and which must surely be due to changes in the density of the steam-water mixture beneath the water-level in the boiler as the load varies. The second is true foaming or the filling of the space in the steam drum above the water-level by a mass of bubbles, presumably small in size. (The conclusion as to the relative size of these bubbles seems warranted from the very large quantities of water which they hold, from which it follows that the ratio of bubble surface to bubble content must be great.) While under certain conditions true foaming may occur without extreme disturbance of water-level, large fluctuations of water-level are usually accompanied by the production of wet steam; whether through the medium of foaming or not it is difficult to say.

It is my belief that these two phenomena arise from different causes or at least through different applications of the same causes. Although a considerable amount of information has been collected concerning these conditions it is still impossible to say more with certainty than that they depend in part upon boiler design, load characteristics, rapid changes in rate of combustion, and the nature of the water in the boiler.

It is not as widely realized as it should be, that a considerable amount of water-level fluctuation and wet steam production may be eliminated by proper combustion control. In a group of boilers subjected to a swinging load, one or more boilers often seem to "hog" an increasing load, resulting in foaming or "priming" in these boilers, whereas proper combustion control by dividing the load evenly among the boilers would eliminate this condition. This tendency to "hog" loads is intimately associated with feed-water control as, when one boiler of a group picks up an increased steam demand, the water-level rises temporarily. This results in slowing or stopping the feed-water supply to this boiler with the result that more heat becomes available for steam generation, and the boiler load increases further at the expense of the load on the other boilers. It is apparent then that anything which will prevent an initial inequality in the division of the load will effect a more than proportionate improvement in fluctuation of water-level.

It is well established by the experience of many that water-level response to load variation is accentuated by increase in the concentration of dissolved and suspended solids in a boiler water. Professor Foulk, of Ohio State University, in work referred to previously, came to the conclusion that under conditions studied by him both suspended solids and dissolved solids had to be in excess of 500 parts per million for serious foaming to ensue.

It seems unnecessary to emphasize the fact that it is the characteristics of the boiler water itself, and not the history of this boiler water, which affects water-level and steam quality. Furthermore, until research proves that specific materials or a specific group of materials have a decided effect upon these phenomena, the only basis for judging the behavior of a boiler water under prescribed conditions is the concentration of suspended solids and the concentration of total dissolved solids in this water.

If we consider the boiler waters resulting from the evaporation of (1) a feed-water treated by the base-exchange process; (2) a feed-water treated with lime and soda and filtered before entering the boiler; and (3) the introduction of untreated water to a boiler with internal treatment and filtration of the boiler water, with equal blow down in all cases, it can be shown that the concentration of dissolved solids resulting from the last two is the same, and the concentration of dissolved solids resulting from the first is greater in an amount corresponding to the amount of temporary hardness in the raw water. The concentration of suspended material in a boiler water resulting from the third method of treatment will in practically all cases be smaller than that resulting from the second, and can be made smaller than that resulting from either the second or the first if desired.

In answer to Mr. Reed's questions, it can be said that:

1. It is a matter of common experience among those interested in the treatment of feed-waters and boiler waters that the prevention of scale by treatment results in greater likelihood of wet steam and water-level fluctuation. The greater the amount of scale deposition prevented by such treatment, the greater is this likelihood. Many plants, for example, using Monongahela and Ohio river waters can treat for full scale prevention during the spring without serious difficulty due to wet steam. During the fall, when the dissolved solid

content increases materially, a tendency to wet steam troubles ensues unless scale is allowed to deposit.

2. Decreasing the concentration of suspended solids in a boiler water is an aid in diminishing the tendency to uneasy water-level and wet steam production. It is uneconomical to attempt to effect a sufficient reduction in suspended material by blow down alone. Even with a feed-water containing as little as 2.5 grains per gallon of hardness, none of which forms scale, a very large blow down is often necessary to limit the suspended solids to 500 parts per million. This blow down may be as high as eight per cent.—a figure usually much in excess of that required to hold the dissolved solids in proper limits. Just as the concentration of dissolved solids may be reduced by increasing the blow down, the concentration of suspended solids may be decreased by filtration of the boiler water. An instance of this is the removal by filtration of sludge from a boiler fed with treated and filtered feed-water.

3. The blow down necessary to maintain a definite concentration of dissolved solids in a boiler will vary as the dissolved solids in the feed-water. If we assume that it is desired to carry a concentration of 3000 parts per million of sulphate in a boiler water, the blow down required may vary from 0.2 per cent. to 0.3 per cent. in the case of certain New England waters, to as high as 20 per cent. or even greater for certain well waters in the middle west. The choice of the proper concentration depends partially on a feasible value of blow down, the boiler design, and whether it is desired to maintain the moisture in steam at a low value without the use of steam-purifying equipment, or whether it is merely desired to limit the load on such steam-purifying equipment.

Mr. E. J. Umstead:* I would like to ask if Dr. Hall has developed a method by which a steam engineer unskilled in chemistry can so control his feed-water through this method of treatment that he can get good results?

Mr. R. E. Hall: It has been necessary to develop apparatus with which the engineer unskilled in chemistry can control the concentration ratios in his boiler water. It is essential that he know the

*Division Engineer, Bureau of Water, City of Pittsburgh, Pittsburgh.

concentration of carbonate and sulphate if he is using soda-ash, or phosphate and sulphate if he is using sodium phosphate. For a determination of sulphate, we add acidified barium chlorid to 10 cubic centimeters of boiler water placed in a jar, the walls of which are darkened. Sulphate-free water is then added until a line, illuminated by an ordinary incandescent lamp, becomes visible through the milky solution. The determination is exceedingly simple, and can be made by any unskilled operator in from two to five minutes. For the determination of carbonate, a cabinet has been devised, which contains standard acid and a burette. One hundred cubic centimeters of boiler water are taken, a few drops of indicator (brom-phenol blue in our work) are introduced, and then standard acid is added until the color changes from blue to green. The number of cubic centimeters of acid used, read from the burette, multiplied by 20, gives the carbonate in parts per million. Since we are using the concentrated boiler water, an error of a cubic centimeter in the burette reading is allowable, although quite unnecessary. For the determination of phosphate, ammonium molybdate is added to 100 cubic centimeters of the acidified boiler water in a pear-shaped container ending in a capillary. The mixture is shaken, and then allowed to stand for half an hour. At the end of this time the amount of phosphate in the boiler water is known from reading the depth of yellow precipitate which has settled in the calibrated capillary tube.

These points should be noted: The different pieces of apparatus have been developed and calibrated and the necessary solutions so made up that, so far as the man at the boiler is concerned, the operations are purely mechanical. It will not do, however, for him to try to change the solutions specified, for his calibrations will no longer mean anything. Unless excellent chemical facilities are available at his plant, he will do best to replenish his chemicals directly from the sponsors of the apparatus. Under these conditions, I feel safe in saying that any boiler operator can control the concentrations in the boiler water satisfactorily.

MR. J. B. CRANE: That requires a more capable man than is ordinarily used in the boiler plant.

Mr. R. E. Hall: I don't know about that. At the Bureau our colored fireman takes great pride in "doing his chemistry," as he calls it. It took quite a little time to initiate him into the secrets of it, but he is there to-day.

Mr. L. J. Reed: I would like to ask Dr. Hall whether the use of other treatment such as tannin, castor oil, etc., along with a straight lime and soda-ash treatment would in any way interfere with the action of the latter, and with the relationship of the carbonate and sulphate radicals for proper treatment?

Mr. R. E. Hall: Not so far as I know. Calcium tannate is insoluble, and hence helps remove any calcium in the water. In the presence of these organic chemicals, however, you can not depend on ordinary titration, because you are dealing with the salts of weak acids. Special precautions must be taken to maintain the proper carbonate-sulphate ratio.

Mr. W. L. Piening: Is it not true that sulphuric acid will not mix with water as a rule? I have always found corrosion up about the water-line in all boilers I ever inspected in this district.

Mr. R. E. Hall: Sulphuric acid mixes very readily with water. The corrosion at the water-line is doubtless due to differences in concentration of dissolved oxygen. These differences in concentration result in corrosion, because the iron becomes anodic and dissolves at the point of the lesser oxygen concentration; at the point of greater concentration, the iron is cathodic, and the dissolved oxygen depolarizes this cathode.

Mr. W. L. Piening: During the War I had Jones & Laughlin put zinc in their boilers. When they did that the acid would attack the zinc and eat it up completely and it would not attack the shell of the boiler as much.

Mr. R. E. Hall: The use of zinc is perfectly sound. The only question is this: Can you so distribute the zinc that it will protect the whole of the shell?

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineers' Society of Western Pennsylvania was held in the William Penn Hotel, Tuesday, November 17th, at 4:40 P. M., President W. B. Spellmire presiding, Messrs. Ladd, Fohl, Leland, Weldin, Dornbush, Clark, Alford and the Secretary being present.

The minutes of the last meeting, held October 20th, were approved without reading.

Applications for membership from the following gentlemen, having been published to the Society, pursuant to the action of the Board, were elected to membership:

MEMBERS

Beatty, Floyd Arthur
Cole, Herbert Francis
Richards, Earl M.
Stone, Richard Henry

ASSOCIATE MEMBERS

Foight, Clarence Douglas
Murto, Harry Chalmers

JUNIORS

McQuiston, William Bryce
Myton, Walter S.
Power, Paul C.
Schucker, Paul F.

Applications for membership were received from the following gentlemen and their names ordered published to the Society. Assignment to the various grades is as follows:

MEMBERS

Diehl, David H.
Hanst, J. Faber
Malevich, Vladimir
McInerney, William I.

ASSOCIATE MEMBERS

Keagy, A. D.
Malseed, William H.
Robinson, Mayes Randolph

JUNIOR

Hammer, L. E.

ASSOCIATE

Thompson, Francis R.

Application for transfer to higher grade was received from the following, and Secretary requested to transfer to grade of Member:

Behney, C. C.

Letters of resignation were received from the following gentlemen and, after discussion, they were ordered accepted:

Phelps, S. B.
Stimpson, Clarence A.

The Secretary reported the death of the following members:

S. A. Davis..........................Joined March, 1903—Died Nov. 5, 1925
W. B. Rodgers......................Joined Jan., 1904—Died Nov. 16, 1925

The report of the Secretary, showing the condition of business October 31st, having been audited by the Finance Committee, was approved.

In the absence of Mr. Clifford, Chairman of the Entertainment Committee, the Secretary reported that arrangements were under way for the Annual Banquet and the committee expected to have definite report as to speakers for the December meeting of the Board.

Arrangements are also completed and notices mailed for an inspection trip to the American Window Glass Company on Saturday, November 21st.

Committee have also arranged, in accordance with their program, for another Ladies' Night party on December 11th.

Mr. Leland, Chairman of the House Committee, reported that the attendance in the evening for the month of October was 371. Also that the attendance at our Noonday Luncheons are still increasing, and also called attention to the increase in the evening attendance in the Club Room.

The Membership Committee held one meeting to go over applications and assign them to the various grades of membership and transact all other business coming before the Committee.

In the absence of Mr. Goodspeed, Chairman of the Publication Committee, the Secretary reported that the program as made up by the Comrnttee gave promise of being carried out as planned.

In accordance wtth Section 5 of Article 5 of our By-Laws, the following report of the Nominating Committee was presented:

To the Board of Direction,
Engineers' Society of Western Pennsylvania.

Dear Sirs:

The Nominating Committee appointed to nominate officers for the ensuing year held a meeting in the Society Rooms, November 13th and 17th, and beg to submit the following members as nominees for the offices indicated:

President	W. E. Fohl
Vice President	John A. Hunter
Treasurer	A. Stucki
Directors	L. C. Edgar H. N. Eavenson

Respectfully submitted,

William Archie Weldin,
Sydney Dillon,
John I. Thompson,
George S. Humphrey,
Graham Bright, *Chairman,*
Nominating Committee.

It was regularly moved and carried that the report be approved and the names published to the Socety in accordance with the By-Laws.

The President called attention to the all-day conference conducted by the Steel Works Section on Thursday, November 12th, stating that the total expenses had been \$513 and receipts \$271, a net expense of \$242. Four papers were presented at the conference, and had they been presented at regular evenings the total expense would have been in the neighborhood of \$500.

Mr. Spellmire asked that the Board think this matter over, as the Steel Works Section held this meeting as an experiment, with the idea that if it proved a success other Sections of the Society might care to hold similar meetings.

The attendance at the sessions have been in the neighborhood of 200 and a very representative list of visitors was in attendance, several coming from Chicago, Cleveland, Gary and other distant points.

The Secretary presented a letter from Mr. Snell, Secretary, The Chamber of Commerce, asking our Society to endorse the action taken by the

chamber in urging that Pittsburgh be represented at the Sesqui-Centennial Exposition to be held in Philadelphia, June to December, 1926.

It was moved and carried that the communication be filed.

Mr. Weldin, representative of this Society on the Better Traffic Committee recently appointed by Mayor Magee, reported on the work being done by the Committee and stated that arrangements had been recently made so that all members of the Committee would, in the future, be conversant with action taken by the Executive Committee and any of the other sub-committees.

Mr. Weldin presented a report covering matters taken up at the last meeting of the Committee and those to come up at the next meeting. It was suggested that these bulletins be posted on our bulletin board and that brief announcements be placed from time to time in our Society Notes giving outstanding features of the work of the Committee.

The meeting adjourned at 5:45 P. M.

K. F. Treschow, *Secretary.*

CIVIL SECTION

The regular bi-monthly meeting of the Civil Section of the Engineers' Society of Western Pennsylvania was held in the Blue Room, William Penn Hotel, Tuesday, November 3rd, at 8:20 P. M., Chairman C. C. Dornbush presiding, 40 members and visitors being present.

The minutes of the last meeting, held September 17th, were read and approved.

There being no further business, the paper of the evening, on "Architectural Practice," was presented by Mr. Edward B. Lee, Architect, Pittsburgh, Pa.

The ensuing discussion was participated in by: G. E. Flanagan, Mech. Engr., Heyl & Patterson, Inc.; Richard Irvin, Architect and Engineer, Pittsburgh, Pa.; J. A. McEwen, Sales Engr., Pittsburgh Bridge & Iron Works; F. K. Howell, Supt., Compressing Stations, Philadelphia Co.; John A. Faulkman, Engr., Morris Knowles, Inc.; P. W. Price, Prin. Asst. Engr., Bureau of Bridges, Dept. Public Works, Allegheny County; W. M. Austin, Engr., Westinghouse Elec. & Mfg. Co.; C. C. Dornbush, Asst. Struct. Sales Engr., Jones & Laughlin Steel Corp.; G. W. Thomas, Chf. Engr., H. H. Robertson Company; and the author.

On action, duly seconded and carried, a vote of thanks was extended to Mr. Lee for his very interesting paper.

On motion, the meeting adjourned at 10:30 P. M.

K. F. Treschow, *Secretary.*

STEEL WORKS SECTION

An all-day conference was held by the Steel Works Section, Thursday, November 12th, in the Blue Room, William Penn Hotel. The meeting was opened by Mr. Walter B. Spellmire, President, at 9:30 A. M., and turned over to Mr. L. C. Edgar, Chairman of the Section, 200 members and visitors being present.

The first paper presented was "Some Observations Regarding Blast-Furnace Design," by Arthur G. McKee, President, Arthur G. McKee & Co., Cleveland, Ohio.

The ensuing discussion was participated in by: Walter Mathesius, Asst. Gen. Supt., South Works, Illinois Steel Co., S. Chicago, Ill.; Julian Kennedy, Consulting Engr., Pittsburgh, Pa.; C. D. Rawstorne, Contracting

Engr., Riter-Conley Company, Pittsburgh, Pa.; A. E. Maccoun, Supt., Blast Furnaces, Edgar Thomson Works, Carnegie Steel Co., Braddock, Pa.; E. E. Evans, Supt., Blast Furnaces, Youngstown Sheet & Tube Co., Youngstown, O.; and the author.

The second paper presented was "Modern Blast-Furnace Stoves," by A. E. Maccoun, Superintendent, Blast Furnaces, Edgar Thomson Works, Carnegie Steel Company, Braddock, Pa.

The ensuing discussion was participated in by: J. C. Barrett, Supt., Blast Furnaces, Carnegie Steel Co., Youngstown, O.; A. J. Boynton, V. P., H. A. Brassert & Co., Chicago, Ill.; L. C. Edgar, Chf. Engr., Edgar Thomson Works, Carnegie Steel Co., Braddock, Pa.; L. A. Touzalin, Supt., Blast Furnaces, Illinois Steel Co., Joliet, Ill.; Julian Kennedy, Jr., Engineer, with Julian Kennedy, Pittsburgh, Pa.; T. J. McLaughlin, Fuel Expr. Engr., Carnegie Steel Co., Duquesne, Pa.; Arthur G. McKee, Pres., Arthur G. McKee & Co., Cleveland, O.; Walter Mathesius, Asst. Gen. Supt., South Works, Illinois Steel Co., Chicago, Ill.; C. D. Rawstorne, Contracting Engr., Riter-Conley Co., Pittsburgh, Pa.; F. B. Thatcher, Asst. Gen. Mgr., By-Products Coke Corporation, Chicago, Ill.; J. S. Unger, Mgr., Research Bureau, Carnegie Steel Co., Pittsburgh, Pa.; and the author.

The third paper presented was "Effect of Physical Properties of Ore and Coke on the Capacity of the Blast Furnace," by Messrs. T. L. Joseph and P. H. Royster, Metallurgists, North Central Experiment Station, U. S. Bureau of Mines, Minneapolis, Minn., and S. P. Kinney, Supervising Ferrous Metallurgist, U. S. Bureau of Mines, Pittsburgh, Pa.

Written discussion was presented by: Walter Mathesius, Asst. Gen. Supt., South Works, Illinois Steel Co., S. Chicago, Ill.

The ensuing discussion was participated in by: John S. Unger, Mgr., Research Bureau, Carnegie Steel Co., Pittsburgh, Pa.; A. E. Maccoun, Supt., Blast Furnaces, Edgar Thomson Works, Carnegie Steel Co., Braddock, Pa.; T. L. Joseph, Metallurgist, North Central Experiment Station, U. S. Bureau of Mines, Minneapolis, Minn.; Arthur G. McKee, Pres., Arthur G. McKee & Co., Cleveland, O.; A. J. Boynton, V. P., H. A. Brassert & Co., Chicago, Ill.; A. C. Fieldner, Supt., Pittsburgh Experiment Station, U. S. Bureau of Mines, Pittsburgh, Pa.; L. A. Touzalin, Supt., Blast Furnaces, Illinois Steel Co., Joliet, Ill.; Walter Mathesius, Asst. Gen. Supt., South Works, Illinois Steel Co., S. Chicago, Ill.; J. C. Barrett, Supt., Blast Furnaces, Carnegie Steel Co., Youngstown, O.; and the author.

The fourth paper presented was "A Method of Determining Comparable Blowing Practices for Iron Blast Furnaces," by J. S. Fulton, Special Representative, Ingersoll-Rand Company, Pittsburgh, Pa.

Written discussion was presented by: Walter Mathesius, Asst. Gen. Supt., South Works, Illinois Steel Co., S. Chicago, Ill.; F. B. Cutler, Chief, Bureau of Steam Engineering, Tennessee Coal, Iron & R. R. Co., Ensley, Ala.

The ensuing discussion was participated in by: W. P. Chandler, Jr., Special Engr., Carnegie Steel Co., Pittsburgh, Pa.; and the author.

The conference adjourned at 10:30 P. M.

K. F. Treschow, *Secretary.*

JOINT MEETING
ENGINEERS' SOCIETY OF WESTERN PENNSYLVANIA, GENERAL SOCIETY,
And
AMERICAN SOCIETY OF CIVIL ENGINEERS, PITTSBURGH SECTION

The 435th regular monthly meeting of the Engineers' Society of Western Pennsylvania was held jointly with the Pittsburgh Section of the American Society of Civil Engineers in the Ball Room, William Penn Hotel, Friday, November 20th, at 8:20 P. M., President Walter B. Spellmire presiding, 624 members and visitors being present.

The minutes of the last meeting, held October 20th, were read and approved.

The Board of Direction reported the election of four applicants to the grade of Member, two to the grade of Associate and four to the grade of Junior, and the receipt of nine applications for membership. One member was transferred to the grade of Member; two resignations were accepted, and two deaths were reported.

No further business coming before the Society, the paper of the evening on "Modern Radio and Electrical Phonograph Reproduction," was presented by Mr. A. VanDyck, Division Engineer, Technical and Test Department, Radio Corporation of America, New York, N. Y.

A general discussion followed the presentation of the paper.

On motion, duly seconded and carried, a vote of thanks was extended to Mr. VanDyck and Mr. Larson for the very interesting paper and demonstration.

The meeting adojourned at 10:30 P. M.

K. F. Treschow, *Secretary.*

MINING SECTION

The regular bi-monthly meeting of the Mining Section of the Engineers' Society of Western Pennsylvania was held in Room 50, Parlor Floor, William Penn Hotel, Tuesday, November 24th, at 8:23 P. M., Vice Chairman N. F. Hopkins presiding in the absence of the Chairman, 48 members and visitors being present.

The minutes of the last meeting, held September 29th, were read and approved.

No further business coming before the Section, the paper of the evening, on "Failure of Concrete Shaft Linings at Pennsylvania Bituminous Coal Mines," was presented by Mr. N. G. Alford, Vice President, Howard N. Eavenson and Associates, Pittsburgh, Pa.

Written discussion was presented by: R. G. Johnson, Pres., The R. G. Johnson Company.

The ensuing discussion was participated in by: A. C. Irwin, Mgr., Railways Bureau, Portland Cement Asociation, Chicago, Ill.; C. H. Dorsey, Treas., The R. G. Johnson Company; Howard N. Eavenson, Cons. Engr., Howard N. Eavenson & Associates; F. A. McDonald, Gen. Supt. & Chf. Engr., National Mining Co., Morgan, Allegheny Co., Pa.; N. F. Hopkins, Civil & Mining Engr., Harrop & Hopkins; H. M. Ernst, Gen. Supt., Pittsburgh Coal Terminal Corp.; F. R. McMillan, Associate Engr., Structural Materials Research Laboratory, Lewis Institute, Chicago, Ill.; Carl Weber, Pres., Weber Engineering Corporation, New York, N. Y.; T. P. Watson,

Asst. Engr., Chief Engineer's Department, Pennsylvania R. R. Co.; W. A. Weldin, Blum, Weldin & Co.; A. E. Duckwall, H. C. Frick Coke Co., Scottdale, Pa.; E. T. Gott, V. P., Dravo Contracting Co.; A. F. Brosky, Asst. Editor, Coal Age, McGraw-Hill Co., Inc.; F. W. Powelson, Civil Engr., Pressed Steel Car Co.; J. M. Rice, Consulting Engr., Pittsburgh, Pa.; M. E. Haworth, Chf. Engr., Hillman Coal & Coke Co.; P. J. Freeman, Chf. Engr., Tests & Specifications, Allegheny Co.; C. W. Gibbs, Gen. Mgr., Harwick Coal & Coke Co.; and the author.

On motion, duly seconded and carried, a vote of thanks was extended to Mr. Alford for his very interesting and instructive paper.

The meeting adjourned at 10:50 P. M.

K. F. Treschow, *Secretary.*

SOME OBSERVATIONS REGARDING BLAST-FURNACE DESIGN*

By Arthur G. McKee†

The production of pig-iron through all the ages has been a most strenuous enterprise, and the development from the original Cataline forge to the present magnificent furnaces producing 700 or 800 tons a day has been a long course through which the furnace operators have come very slowly for many centuries, but very rapidly during the last few years. The blast-furnace operators of the past thirty years deserve the highest credit for their aggressive pioneering work in the face of enormous difficulties, and, judging from the men who are responsible for the most recent developments, we have every reason to expect the coming decade to see still further advances of very great value to the industry.

During this later period the equipment for producing pig-iron has been wonderfully improved. The practice has been developed and bettered, and a marked improvement in the results has been achieved due to the fact that raw materials are now prepared in very much better condition for use before being charged into the furnace. Ores are now universally crushed to small sizes, limestone or other flux is crushed and thoroughly cleaned, and by close co-operation with the coke makers in the improvement of their equipment and practice, the quality of coke is to-day enormously better than it was a few years ago and we have every reason to expect a very marked further improvement in this direction.

Under the circumstances mentioned above, I propose to talk for a few minutes on the trend of blast-furnace design, hoping that we may then hazard a good guess at what developments may be expected in the near future.

Let us take as a starting point the furnace section typical of 1840, which was given by that wonderful pioneer of the blast-furnace industry, Sir Lowthian Bell, and stated by him to be too low or short for efficient reduction of ore. This furnace is shown in Fig. 1, and you will note that it is very different from what we have to-day, being

*Presented at "Blast-Furnace Conference," November 12, 1925. Received for publication December 8, 1925.

†President, Arthur G. McKee & Co., Cleveland.

rather bulbous in its contour. The furnace as developed by Sir Lowthian Bell and recommended by him as much more efficient is shown

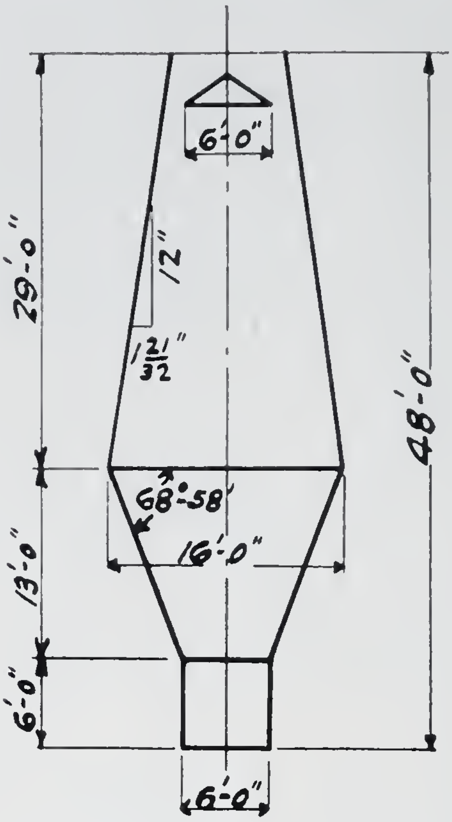

Fig. 1. English Blast-Furnace of 1840.

in Fig. 2. This, you will observe, is of almost the same dimensions

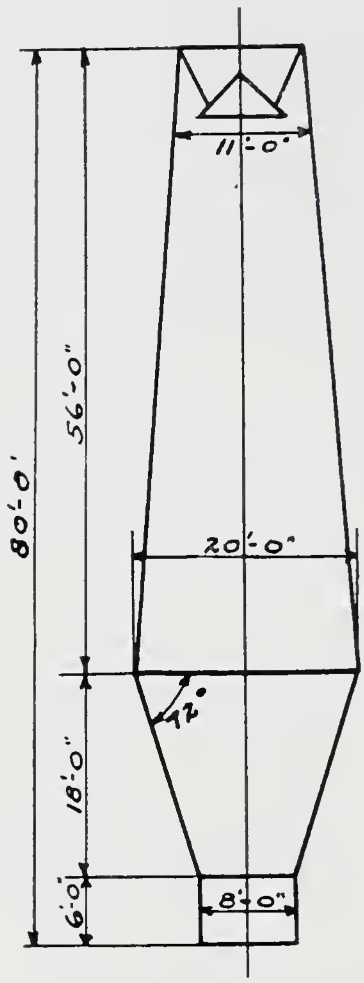

Fig. 2. Blast-Furnace Developed by Sir Lowthian Bell in 1840.

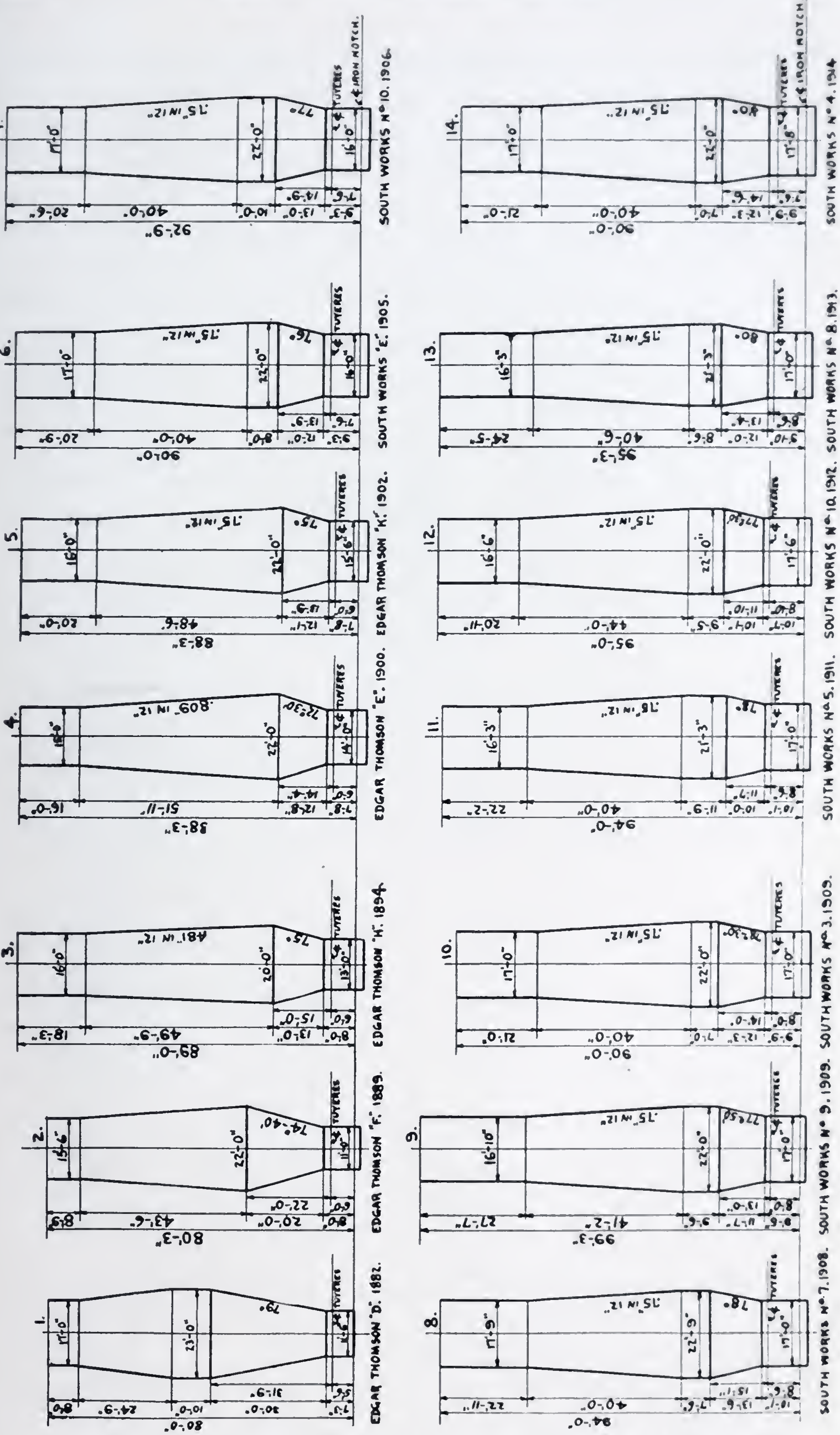

Fig. 3. Development of Blast-Furnace Lines Since 1882.

except that it is taller, having about the same shape, and the same very small hearth.

In connection with this section, it is interesting to keep in mind the fact that this furnace, shown in Fig. 2, ran on blast heated to about 650 degrees F., and had a production of about 17 tons a day or, as he would have said, 120 tons a week. Please note on these furnaces the small hearth, very high bosh and very large top diameter.

Starting with these two, indicative of what was done 85 years ago, and progressing with the development of the furnace industry, we have in Fig. 3 the sections of a series of furnaces, starting with

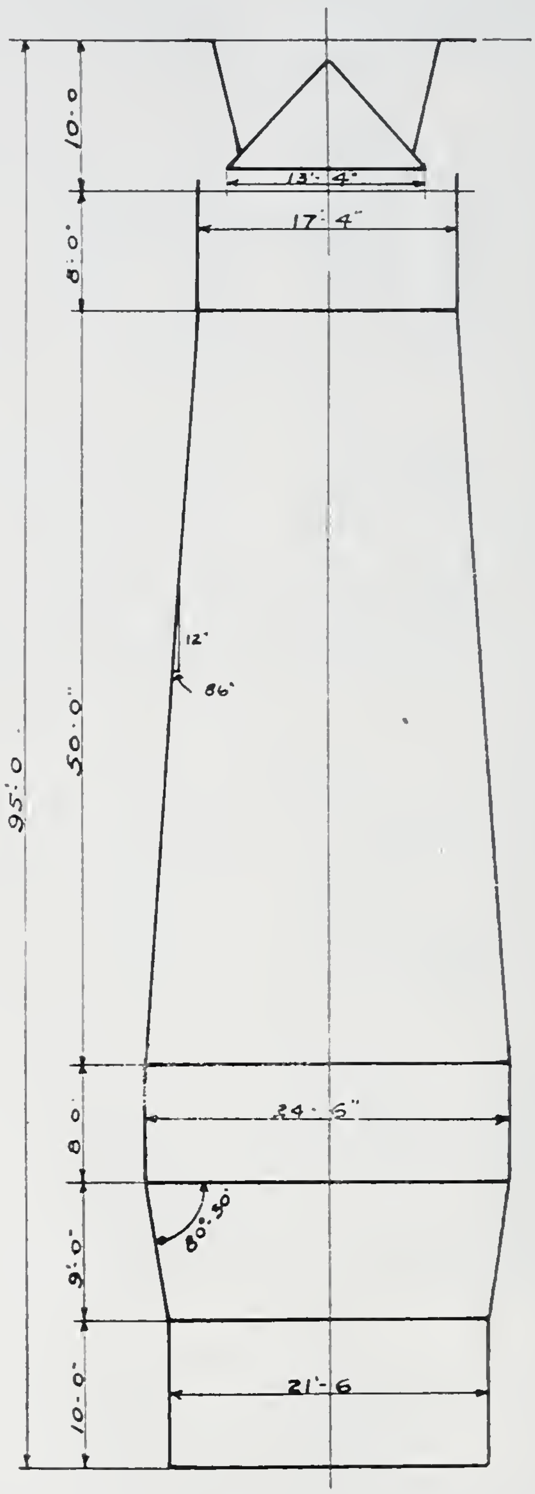

Fig. 4. Typical Modern Blast-Furnace.

Edgar Thomson in 1882 and running through to 1914. This is a study of characteristic sections of furnaces of the several dates given, and would be very interesting had we time to study it more thoroughly. As you notice, the furnaces of 1882 were along the same lines as Sir Lowthian Bell's of 40 years earlier, having much the same bulbous shape, small hearth, high bosh and large top diameter. During the next 20 years the height of the bosh was lowered, and coming down to 1900 we find a 72½-degree bosh, 14 feet, 4 inches high. This was the period of flattening the bosh angle and lowering the height of the bosh; after this time the development was in the direction of a gradually steeper bosh and larger hearth diameter.

In 1914 we have a furnace built at South Chicago, which has departed very largely from the shape of the first furnace considered

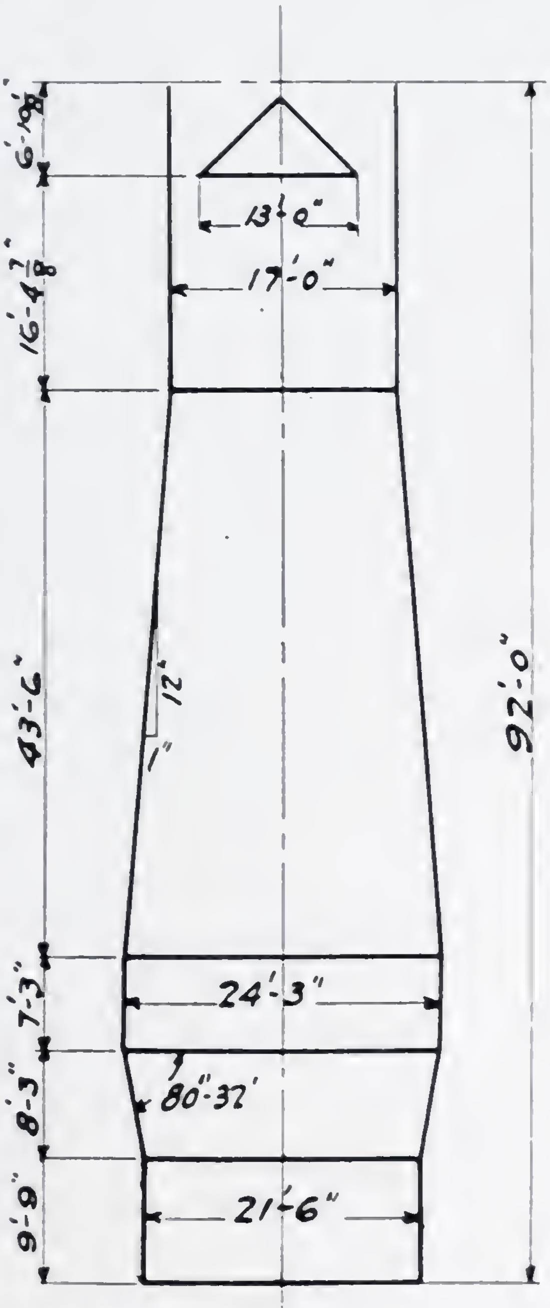

Fig. 5. Blast-Furnace of Illinois Steel Company.

and which has approached very closely to the form of a cylinder, the hearth and top being respectively 17 feet, 8 inches, and 17 feet, while the bosh is 22 feet in diameter. Since that date, the furnace section has deviated somewhat from its previous tendency toward a cylinder. This is shown in Fig. 4, which is a good representation of the standard practice of to-day. You will notice that the lines are still a close approach to the cylinder such as we had in the previous section and the deviation is only to the extent of increasing the diameters of the hearth and of the bosh, leaving the top almost the same as it was, the hearth being 21 feet, 6 inches, the bosh 24 feet, 6 inches and the top 17 feet, 4 inches. Fig. 5 is also typical of the latest furnace of the large type—the Illinois Steel Company's No. 5 furnace, 1924.

The shape of the Sir Lowthian Bell furnace of 85 years ago was dictated by the very slow rate of driving, coarse rock ores and comparatively cold blast. The small hearth and large bosh were believed necessary to hold up the lumps of ore until they were reduced and melted into the very small hearth. Of course, this seems all wrong viewed from our present knowledge, but under the circumstances it is fair to assume that Sir Lowthian Bell was probably about right for conditions as they were at that time. Don't forget that he was blowing very slowly for a tonnage which was almost microscopic.

While output increased materially during the period of lowering the bosh angle from 1880 to 1900, the difficulties of operation increased seriously, and in the period from 1900 to 1908 running a blast-furnace was a most hazardous calling. Slips, explosions and bottom "breakouts" were constant occurrences, with serious and often fatal results to one or more of the operators. At that time anybody who had anything whatever to do with a blast-furnace certainly led a very hard life. One superintendent succeeded another at frequent intervals, the labor turnover was enormous and the one thing really accomplished was the great increase of output to 500 tons daily, first realized at the Edgar Thomson and the Duquesne works of the Carnegie Steel Company, and later equaled at other plants as they were modernized. This was really a wonderful achievement for that time and the truthfulness of the records was questioned all over the world.

We know now that the flat bosh was all wrong and gave very bad operating results, but the coincident increase in hearth diameter and heavier blowing made possible the large output. The further

increase of hearth diameter with the return to a steep bosh angle soon removed many of the operating difficulties and set us on the way to the first stack of large output which it was possible to operate smoothly and efficiently.

Of course, the accompanying improvement of the auxiliary equipment was revolutionary, and contributed largely to the better results. Improved blowing equipment and, particularly, higher blast temperatures have been most potent factors. All of these improvements have brought the industry to a state which fully justifies the recent remark of an English iron-master, who said, "I am astonished at the way in which you have eliminated the uncertainties of the industry." Well may he marvel at the improvement in practice and equipment; it is most gratifying. If we are to improve still further, we may well ask, along what road shall we proceed?

It is well to note that the top diameter of the furnace or stock-line has changed only very slightly since "D" furnace at Edgar Thomson was built in 1882 with 17 feet, and I believe that 17 feet, 4 inches is probably the largest top diameter now in use. While the top diameter has not really been increased at all in 45 years, the amount of blast has increased from 10,000 or 15,000 cubic feet per minute to nearly 60,000. The hearth has increased from 11 feet to 22 feet. This is four times the area or almost in exact proportion to the increase of wind volume. The voids in the furnace stock have decreased considerably on account of the use of large amounts of fine ore in many of our furnaces. In other words, we have increased the hearth and bosh areas in proportion to the increased blast volume, while the top area has not been changed to meet these new conditions. The most serious difficulty resulting from this condition is the extensive production of flue-dust.

Two schools of operation have developed—those who blow for tonnage, disregarding the losses and expense due to the production of flue-dust, and those who blow for a low net cost of iron and a minimum of flue-dust loss. The first school is blowing in some cases nearly, if not all of, 60,000 cubic feet of free air per minute, and, unless they are blessed with an unusually high percentage of Old Range or crushed rock ore, their flue-dust losses are high—some of them very high. The other school is blowing about 40,000 cubic feet, using higher temperature (about 1500 degrees F.) and getting some-

what lower tonnage, but with negligible flue-dust losses and very low coke consumption.

As an example of the furnace advocated by the first school with satisfactory results, please note Fig. 5, which is typical of the latest furnace for large output—the Illinois Steel Company's furnace. Fig. 6

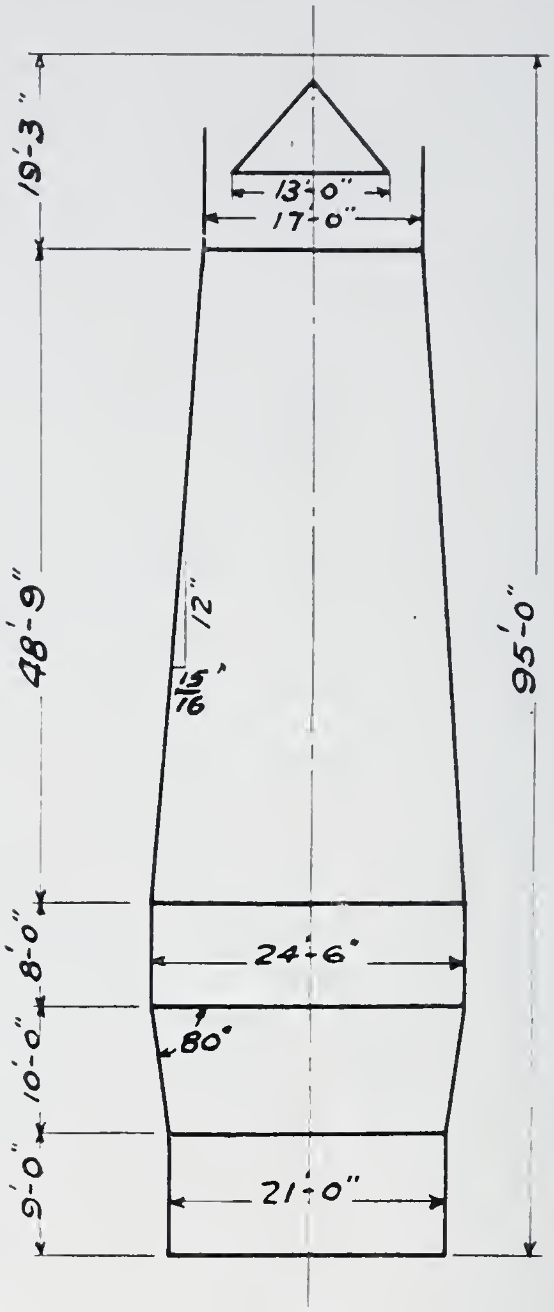

Fig. 6. Blast-Furnace of Toledo Furnace Company.

is another good example of this type—the "B" furnace of the Toledo Furnace Company, built in 1925. It is showing lower flue-dust losses on account of using a large percentage of Old Range ore. The daily production of this furnace averages over 600 tons on No. 2 foundry iron. I understand that the coke consumption is between 1800 and 1900 pounds, truly a remarkable performance.

As the best example of the furnace used by the second school, we will consider the No. 3 stack of the Shenango Furnace Company,

built in 1922 and shown in Fig. 7. This is, as you will notice, a decided departure from the tendency of most other furnaces. Please note that the hearth diameter is almost exactly the same as the stock-line diameter, but the cylinder above the bosh is unusually long and the inwall batter is 1⅛ inches per foot. This furnace is reported as

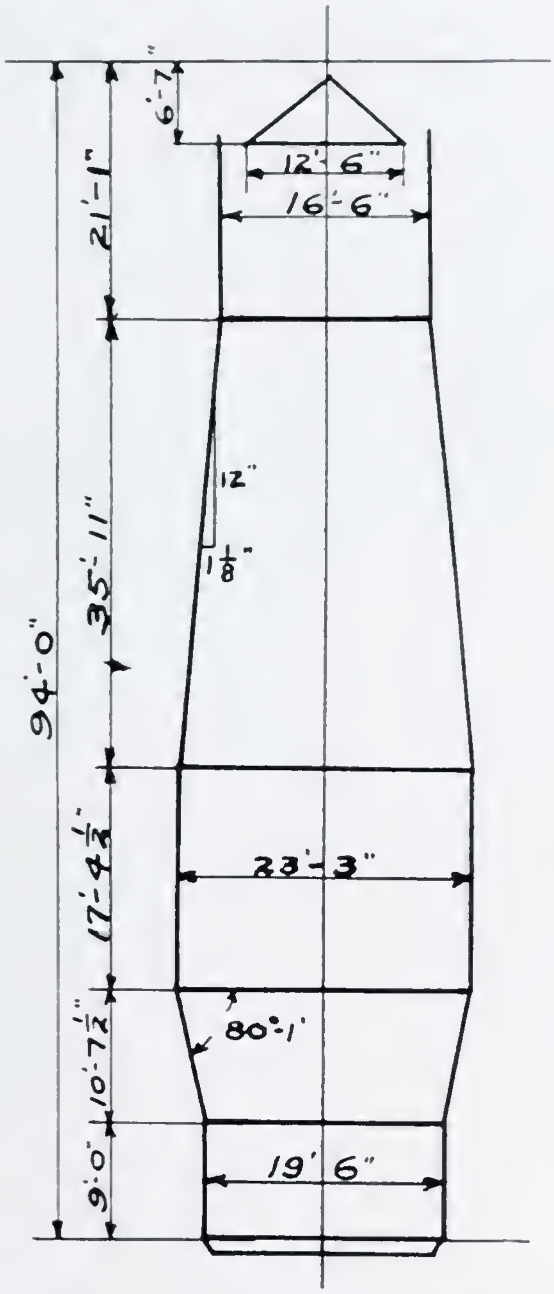

Fig. 7. Blast-Furnace of Shenango Furnace Company.

running on very dusty ores, blowing less than 38,000 cubic feet of air at 1500 degrees F. straight line heat and making approximately 600 tons a day net ore reduced at a fuel consumption of 1853 pounds of coke per ton of iron. This is very satisfactory work, and it is still more so in view of the fact that while the furnace is making about 125 pounds of flue-dust per ton of iron, it is charging all of this back into the furnace in a raw state and thus the net flue-dust production is zero.

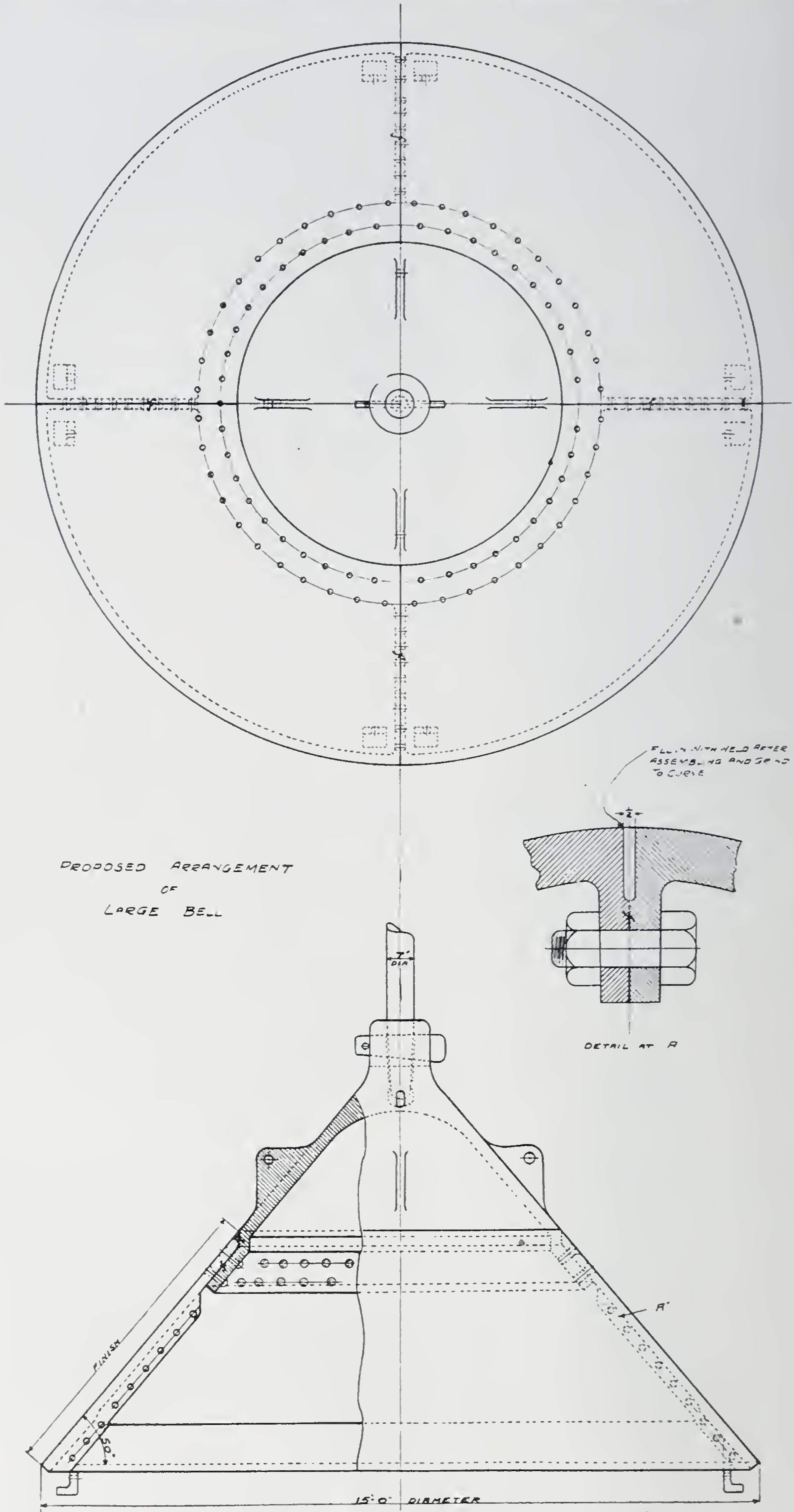

Fig. 8. Proposed Arrangement of Large Bell.

To come to a further consideration of the trend of developments, we find that from 1840 to the present time the bottom of the stack has distinctly trended from a bulb shape to a cylinder and the top has not changed materially. This lack of change is for a curious reason. We can hardly blame it on the income tax, but we can come pretty close to blaming it on the Interstate Commerce Commission, or its vassals, the railroads.

It is generally believed that a bell should be made in one piece, and the railroad clearances will not pass a bell larger than 13 feet, 4 inches. As experience indicates very plainly that the stock-line diameter should not be more than four feet greater than the bell, we have the railroads fixing this very important feature of all of our largest furnaces. If a top of 16 feet, 3 inches, like Shenango No. 3, can take a blast of 38,000 cubic feet and produce about 125 pounds of flue-dust—all of which it can consume without indigestion—is it not reasonable to ask whether a furnace having a 20-foot top, or over 50 per cent. more top area for the passage of the gases, might not pass 57,000 cubic feet and also consume all of its flue-dust and produce 800 tons of pig-iron daily? Of course, this would make necessary the use of an assembled bell, but a bell such as shown in Fig. 8 should be permanently satisfactory regardless of size. This bell is made with a steel center with a skirt riveted to it, this skirt to be accurately machined, then delivered to the furnace, riveted and bolted together and the joints filled in by welding with acetylene or electric burner, thus making the bell into one solid piece. One of my very good friends tells me that he has never had trouble with warping of bells or hoppers since he has had them thoroughly furnace annealed, and a bell such as proposed above should certainly be so treated.

Summing up our conclusions from what we have just seen, it seems clear that the definite trend is, and should be, toward a cylinder from top to bottom, and we would suggest the possibility that a furnace like either of those shown in Fig. 9 might logically be the next step and might give excellent operating conditions in other directions, and at the same time minimize flue-dust troubles. Note the large hearth, the low steep bosh, the long cylinder above the bosh line, the large batter in the inwall and radically large stock-line and bell as shown on the sketch to the left; also the less radical contour of the

stack to the right. The first follows the lines of Shenango No. 3, and the other follows those of other practice.

I know we will all be greatly interested in the discussion of all of these conjectures by those here who have been thinking along these

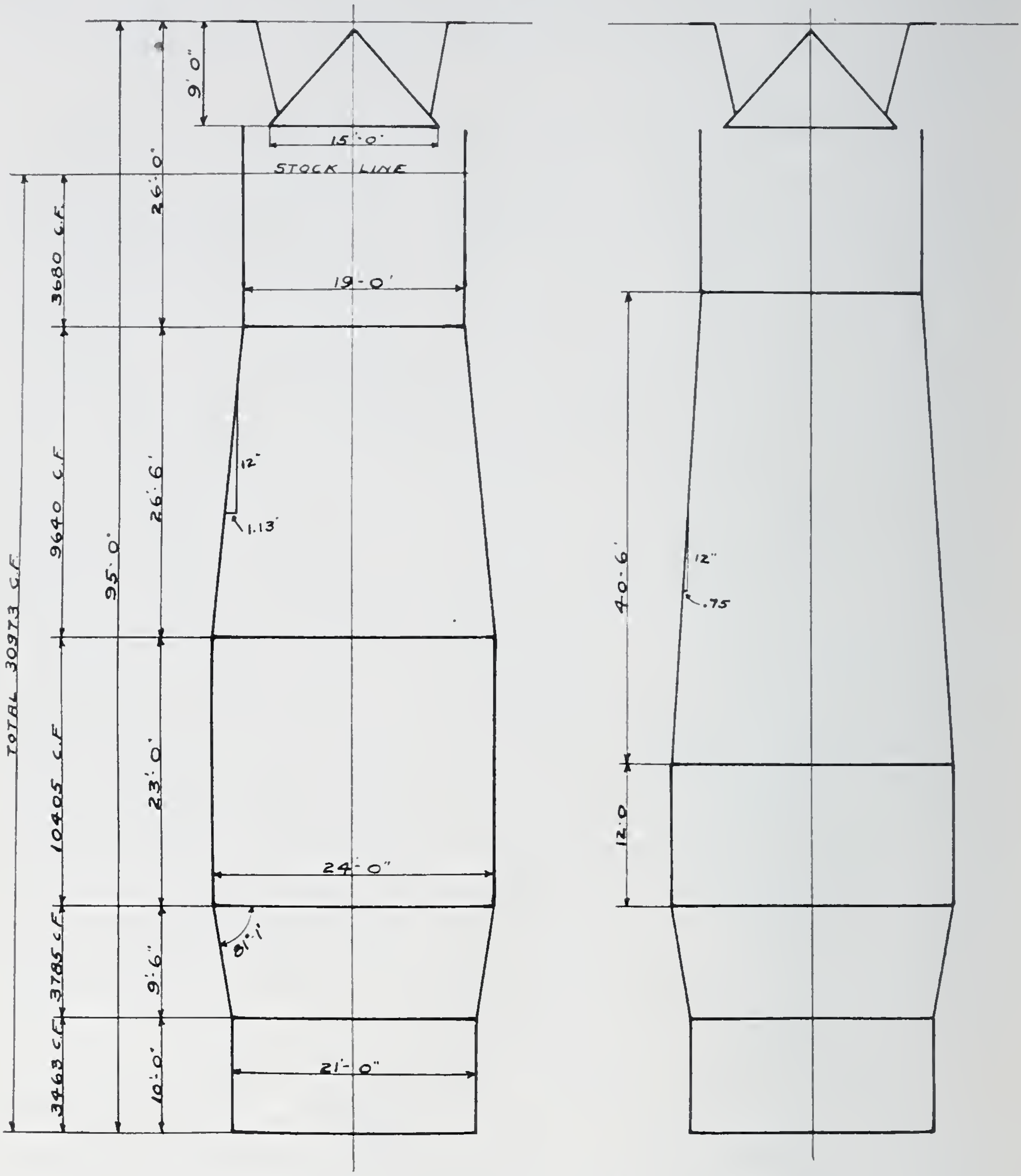

Fig. 9. Possible Future Development of Present Trend in Furnace Lines.

lines, to the end that this discussion may possibly contribute somewhat to the progress of the industry.

Time does not permit much consideration of any of the auxiliary equipment, but it may be worth while to mention briefly the items making up the furnace itself.

Furnace columns, mantle and shell have not changed greatly except in being larger and stronger than formerly.

Hearth jackets are now usually made of heavy riveted steel plate lined with cast-iron plates, containing pipes through which water is circulated. Such a jacket is very strong and is usually proof against "breakouts" and similar troubles of the olden times.

Tuyere breasts of steel plate are a great improvement over the old buck-stays and are very generally satisfactory.

Bosh bands are the same as of old except that they are heavier. Bosh cooling plates have been changed but little in design or distribution in many years, except that the present tendency is to put in too many plates and cool the bosh more than is really necessary, which is, of course, a waste of heat. Plates 21 inches bottom to bottom, just above the tuyeres, are quite close enough and these may safely be spread to 24, 27 and 30 inches as they approach the mantle elevation. They should, of course, be staggered to prevent vertical channeling. Cooling plates for a considerable distance, at times even 40 feet above the bosh line, were almost universally used from 1905 to 1915, but are less and less in evidence, so that comparatively few furnaces are now provided with them.

Tuyeres are, of course, much larger than formerly, but their size and length are a matter which I should prefer to defer to the better judgment of the operators. Twelve tuyeres are preferred by most operators and seem to give excellent results.

Stock-line protection is a most necessary feature of our modern linings where long blasts are the almost universal rule, instead of the exception as of old. Various forms have been used with varying success, but the consensus of opinion seems to be in favor of heavy steel blocks of suitable form, built into the brickwork. These give very satisfactory results, but are quite expensive. These steel blocks should be thoroughly furnace annealed to avoid distortion, loosening of brickwork and other troubles. This annealing may be thoroughly done at very low cost and should contribute to long life and the reduction of troubles of various sorts.

Downcomers are of various designs, but it seems that more attention might be given to making the downcomer openings out of the top of the furnace as large as possible. It is certainly true that the slower the movement of the gases into the downcomer openings the

less the flue-dust produced. Fig. 10 shows a design we have used for many years with excellent results, giving as it does an unusually large opening at the inner surface of the dome lining. Still larger openings may be provided by still further study of this design. We have also used for several years a baffle in the turn of the downcomer pipe

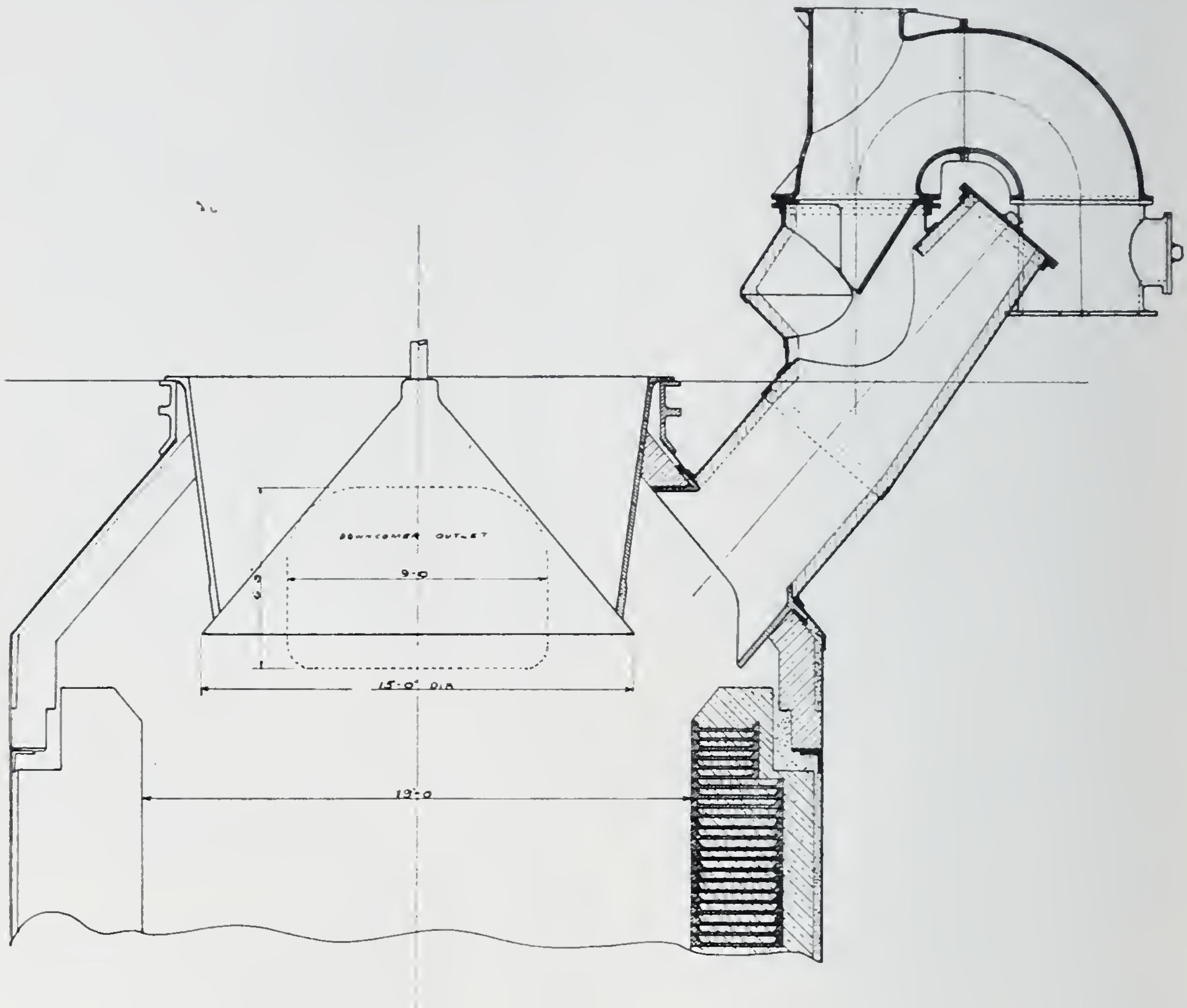

Fig. 10. Section through Furnace Top, Showing Downcomer Connection.

which absolutely prevents any coarse materials from getting past into the dust-catcher as shown in Fig. 10. We have found it to be very effective, and it obstructs the top of the furnace less than the so-called high offtakes now so generally used. In Fig. 10 is also shown a large bell 15 feet in diameter, and top 19 feet in diameter, these diameters being 18 inches greater than any used heretofore. This we believe to be worthy of careful consideration as the next step in the interest of larger outputs with lower flue-dust losses.

I do not want to seem to advertise our own wares, but, as some of you may know, I personally have made a very careful study of

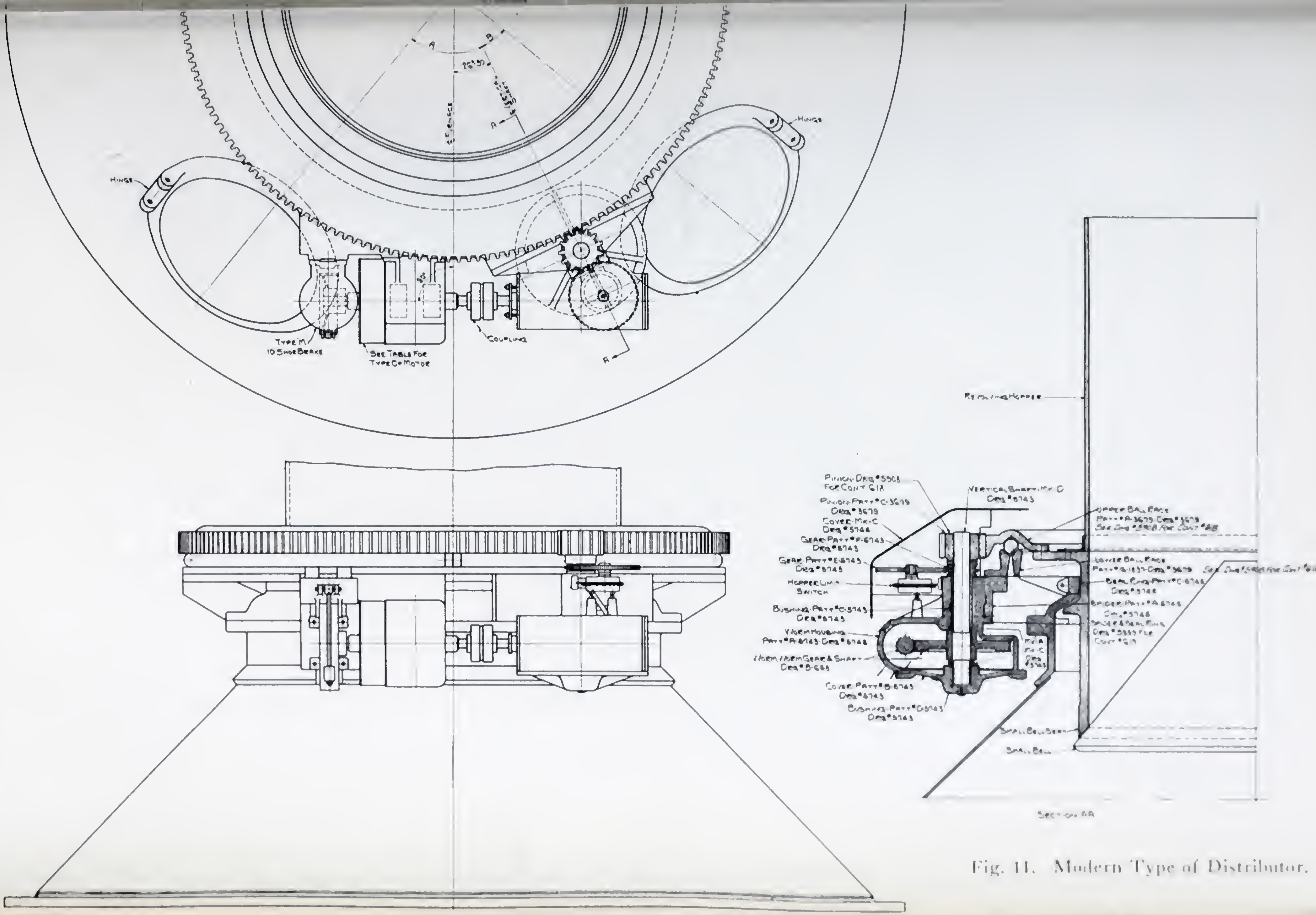

Fig. 11. Modern Type of Distributor.

blast-furnace distribution for many years, and may possibly be pardoned for mentioning this matter here.

After a large number of experiments many years ago in the effort to perfect distribution by preventing segregation, we hit upon the expedient of accepting the segregation as unavoidable but very constant. By overlapping these segregations or irregularities in regular sequence a perfect average was obtained. This was found to work satisfactorily and has been rather generally adopted and the device for effecting this overlapping operation has been improved from time to time. In its latest form this distributor has a self-contained motor drive with worm and gear running in oil as shown in Fig. 11; small ball races of heat-treated nickel steel, ground to form; especially accurate, hardened, alloy-steel balls; large ball races of "Adamite"; small bell, revolving hopper, and covers for small bell rod of accurately finished and hardened manganese steel; thus each part which is subject to wear is made of the very best material for its service. In this form it seems to meet with even more general favor than before.

Please allow me to bring more particularly to your attention a detail of construction which I believe to be most important in our striving for better distribution. A large bell hinged to the bell rod is very easily affected by a greater weight on one side than on the other. One hundred pounds excess will tilt a bell badly out of plumb as it is lowered, and serious irregularities may be developed at this point even though the revolving distributor may be functioning perfectly. I do not know who first made a rigid connection between the large bell and its rod, but whoever he was he certainly was a clear thinker with the courage of his convictions. This construction as shown in Fig. 8 has been used on a considerable number of furnaces for several years past with such excellent results that its universal use is now strongly urged in the interest of better distribution of the stock.

I hope that furnaces may soon be built with larger tops and bells and that we may determine from their use whether our conclusions as stated above are correctly drawn from the facts as now known.

DISCUSSION

Mr. W. Mathesius:* I was very glad to receive the invitation to attend this conference to-day, and have accordingly spent a little time in preparing a discussion on some of the papers which are to be presented. I did not, however, have an opportunity to become acquainted with what Mr. McKee was going to present. I hardly feel able, without preparation, to do justice to his excellent talk. Therefore, if I can loosen the tongues of others present with a few introductory remarks, I think I will have done all that can be expected of me.

At South Chicago we have been much interested in the development of furnace profiles, and we have not let a chance go by to try something new. While we have thus tried to utilize every opportunity to deviate from former practice, we have, nevertheless, diligently checked the results of every new design that has been put on the drawing-board and put into operation by duplicating it in a second unit.

Mr. McKee has mentioned changes that have to do largely with the dimensions of the lower part of the furnace. We have concentrated our efforts on that particular phase, because we felt that the drawbacks to our practice were largely caused in the lower part of the furnace; so it seemed a matter of good judgment to spend money in this direction because this promised the largest financial reward.

I am heartily in accord with Mr. McKee's opinion that changes from the established dimensions in the upper part of the furnace will likely produce results materially different from what we are getting to-day. It is rather interesting to me that Mr. McKee should make this suggestion, because he has been responsible for having eliminated, through the design of his distributor, one of the most frequent causes of excessive flue-dust losses, which are almost invariably due to what we call "lopsidedness," or segregation of the materials, which at times is unavoidable with stationary top equipment.

In that connection, perhaps a word of caution would be in order in thinking of greater diameter in the stock-line. We all know that we are depositing (and deliberately so) fine materials adjacent to the

*Assistant General Superintendent, Illinois Steel Co., South Chicago, Ill.

periphery of the furnace, and that we are experiencing a gradual opening up of the stock column towards the center. I think we do this deliberately, realizing that it is essential to offset the natural segregation of the materials in the opposite direction, which takes place in the travel of the material toward the hearth. I can readily conceive that with a material increase of the stock-line dimensions, the degree of segregation at the stock-line will be materially different from what we have to-day; and, for the best results, this will likely cause corresponding changes in the design of the lower part of the furnace, so as to approach what we consider the best possible relation—that which gives for every foot of cross-section of the furnace, and in relation to its total height, as nearly as possible an equal resistance to the ascending gases.

As I said before, we have endeavored to get results first by altering the dimensions of the hearth and bosh, and have spent money there, thinking that by so doing we would get the larger return. The furnaces we are operating to-day are, of course, constantly producing flue-dust, and we have at the South Chicago works a flue-dust stock pile which has been there for 20 years, at least; but it has not been added to in 13 years, to my knowledge, and we have currently consumed our flue-dust, in my opinion, without detriment of any sort. As a matter of fact, our larger furnaces use, right along, more flue-dust than they are producing, and we are gradually recovering from the old stock pile.

Mr. Julian Kennedy:* I had no inkling of what this would be, and therefore have no preparation, but would like to comment on one or two features.

First, as to the stock-line of the furnace, no one has ever obtained a stock-line that is right, but they are getting better all the time. What we need is a stock-line that will stand sharp scrap that comes in sharp pieces four or five feet long. It is very desirable to have a smooth surface. It is very difficult to get anything that will stand a five-year blast without warping and showing points where the scrap can not pass. We have metal blocks built in, but they are not ideal and we are still apt to get warpage.

*Engineer, Pittsburgh

I think the larger openings into downcomers are a very good thing. The last furnace I built, I bifurcated each of the downcomers on the inside of the dome of the furnace, and then constricted the downcomers on the outside so as to avoid the tendency of the gases to go out at one downcomer.

A wider top is likewise very desirable; and, likewise, I think it desirable to keep a very good slope to the inwall, as this causes the stock to settle more smoothly and diminishes the amount of dust blown out at the top.

I am very much pleased with the paper presented and regret that I haven't more ideas to offer at this time. The production of the Toledo furnace has been mentioned; last month it produced an average of 711 tons of iron, with average silicon 2.37; coke per ton, 1834 pounds; volume of blast 49,000 cubic feet, and a pressure of 14 to 16 pounds.

Speaking of blowing the furnace on two stoves, there is one bad feature in this, namely, that like blowing a furnace with one blowing engine, if anything happens involving the stoppage of the engine, the furnace is stopped entirely. Of course, in a two-furnace plant, if two stoves could be given to each furnace and a fifth one arranged to work in either direction, this objection would be met.

MR. C. D. RAWSTORNE:* We are very fortunate right now, in building four furnaces in which the top designs are entirely different. One in Chicago has four high bleeders, carrying all the top structure. Another at Massillon, Ohio, has four smaller bleeders and structural top. Another at Johnstown, Pa., has both heavy, high bleeders and heavy structural support. Another at Troy, N. Y., very unlike the others, has one bleeder only and structural "A" frame. Another feature is the design of skip trusses and top rigging. We are more or less inclined to go back to the skip bridge, supported on the furnace, the cantilever structure not having proved the best thing, for the reason that the cantilever structure carried the bells and hoppers, and when the furnace settled, as it generally does, the skip pushed against the furnace. It threw the bell out of center and caused other troubles.

The design which now seems to be favored is a simple span, supported by short links or struts, the bells being carried on the structural

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support on the furnace. As the furnace settles, there is enough leeway between the sides of the hopper and the dumping point of the skip to prevent the skip load from spilling outside of the hopper, and the revolving top takes care of any uneven filling of the hopper.

MR. ERNEST EVANS:* We are remodeling our furnace at Youngstown. The original was 88 feet in height, with 22-foot bosh and 16-foot hearth. We are tearing out the old outfit entirely, but leaving the height the same, putting in a hearth of 20 feet, 6 inches and a bosh of 23 feet, 6 inches. We are also relining our stoves, and substituting checkers that will give a substantial increase from 46,000 to 57,000 square feet. We have one furnace, remodeled about a year ago, running about 700 tons a day on Bessemer iron. The coke consumption is about 1950 pounds. It is 88 feet in height, with a hearth of 18 feet, 6 inches, and a bosh diameter of 22 feet, 6 inches.

MR. ARTHUR G. MCKEE: Mr. Rawstorne's remarks regarding the supporting of the bell beams I think are well taken. I believe the closer we can tie the bell supports to the furnace itself the better off we will be. In other words, we should support our bell-operating mechanism entirely on the supports on top of the furnace; then, if we have any settlement or movement of the base, this will at least keep the bells as nearly central with the hopper as possible.

I appreciate Mr. Kennedy's suggestion as to the stock-line. That is a matter to which we have all given a lot of thought, and, so far as we can tell, nobody has yet discovered a way of making a stock-line which is entirely satisfactory. I think a further study along this line, as suggested by Mr. Kennedy, will be valuable and make it ultimately possible to get a very long blast without the disturbance which results from bad stock-line condition.

MR. A. E. MACCOUN:† I want to tell Mr. McKee how I appreciate his paper.

In the development of the modern blast-furnace, Mr. McKee started with 1840 and led up to the present blast-furnace, all of which

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†Superintendent of Blast-Furnaces, Edgar Thomson Works, Carnegie Steel Co., Braddock, Pa.

is very interesting and instructive, but I believe he should have mentioned some other things in connection with their development. I believe it was Gayley who first developed the 500-ton furnace at the Edgar Thomson works, and later that production was exceeded. I don't think a meeting of this kind would be complete without mentioning Mr. Gayley's name. Before Mr. Gayley's time, I believe Mr. Kennedy made quite a few improvements, and I feel his name should be mentioned; and (possibly because of modesty) Mr. Mathesius didn't mention what he has done with regard to the development of furnace lines, although he has certainly done some good work.

I was very much interested in what Mr. McKee said about the Shenango furnace. I don't know whether you noted that straight part above the mantle. I think it was something like 17 feet, but that interested me as a sort of new development. It looked to me to be rather good, and I wrote Mr. Acherson about it. I found that Mr. Acherson tried a straight section on one of his furnaces with good results and he might tell us something about that.

I differ a little with Mr. Kennedy in that I think it a pretty good thing to have a straight section, but we will have to try some of these things, as Mr. Mathesius has said.

These are just a few of the things I wanted to touch upon before taking up blast-furnace stoves.

MODERN BLAST-FURNACE STOVES*

By A. E. Maccount†

The modern blast-furnace is expected to produce approximately 700 tons of iron daily. Its size is approximately 21 feet in hearth diameter, with 24-foot bosh, and a height of approximately 100 feet. The amount of wind required for a furnace of this kind varies under different circumstances from 55,000 to 65,000 cubic feet per minute. To obtain the best coke practice and most efficient work from such a furnace there should be at least 1400 degrees of heat for the blast available at all times, as it is very important to have a large furnace of this kind backed up with plenty of heat. There are now in operation many furnaces of this kind using high heats successfully. The total heating surface required in the stoves for a furnace of this size, allowing for some reserve in case a stove has to be taken off for repairs, should, therefore, not be under 360,000 square feet. It is understood, of course, that the fuel for such stoves is clean gas, as no one would consider using dirty gas in furnace stoves at the present time; that the stoves be equipped with modern gas burners; and that stack temperatures for best efficiencies be not over 500 degrees F.

Regarding the type of stove, it is generally conceded that the two-pass stove, either of the side-combustion or central-combustion type, is preferred by most blast-furnace operators on account of its simplicity of construction and up-keep. From a standpoint of relative amount of heating surface in a given shell and with a given amount of brick, the use of brick and of space is apparently more economical in the two-pass stove than in other types. There is also an advantage in having the valves on the ground level, which is the case with the two-pass stove.

Square checker openings, built of standard brick shapes, are preferred, to eliminate extra shapes in brick, as standard brick should be used as much as possible in all blast-furnace construction. Most operators prefer a brick not under 2½ inches in thickness and a checker opening from 4½ to 5 inches square, as many stoves built of brick two inches in thickness, or less, and having checker openings four inches

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†Superintendent of Blast-Furnaces, Edgar Thomson Works, Carnegie Steel Co., Braddock, Pa.

square, have given more or less trouble by settling or sinking and partially closing up the openings, necessitating the relining of the stoves.

Regarding equipment of stoves, every effort should be made to make the stove tender's work as easy as possible. If this is done, there is no reason why one hot-blast man can not attend to the stoves for two furnaces; whereas, where stove equipment is not so arranged, he has a hard job looking after one set of stoves. This means there should be one central operating house where all heat gages, etc., are available, and from which nearly all stove valves and the mixer-valve can be controlled. This is the aim at many modern blast-furnace plants at the present time. To do this, all the equipment on a stove, such as cold-blast valves, gas doors or valves, hot-blast valves, draft doors, etc., must be arranged so they can be operated mechanically with a minimum exertion, and preferably from the central operating station, wherever this is possible.

Proper design of cold-blast lines, hot-blast lines, and bustle-pipes should also be considered in connection with the increased amount of wind necessary to blow a modern blast-furnace properly. It is important that these mains be made sufficiently large, as at many plants where larger furnaces have been built the drop in blast pressure from the engine room, through the old main system to the tuyeres at the furnace, is excessive, on account of the increased amount of wind blown. This line resistance should be cut down as much as possible to avoid having higher furnace pressures than necessary.

One of the most important developments in the last few years has been more efficient burning of the gas. This requires stove combustion chambers sufficiently large, and a burner from which we can secure proper mixing of furnace gas. A burner of this kind requires regulation of air to meet variable gas pressures and volumes. This can be accomplished only by a burner that regulates the gas, or air, or both. Many furnace plants that have equipped their stoves with burners of this type have greatly improved their combustion efficiency, and have been able to secure better furnace practice by carrying higher heats; as a regulating burner of this kind, when properly set, works continuously and gives proper mixtures at all times, without depending in any way upon the human element for its successful operation.

The Mathesius gate type of hot-blast valve, which is being

adopted at many plants, has helped to simplify stove equipment and decrease repairs required in hot-blast pipe connections. Also, draft valves are being simplified and designed so that they are very easily operated, whereas formerly the operation of these valves was a very laborious part of the stove tender's work.

On many of the modern stoves, mufflers are provided for blow-offs, or the stove pressure is relieved directly into the stove stack. Mufflers are also provided for "snorters" on cold-blast lines. These improvements materially decrease the noise attending the operation of a blast-furnace.

An automatic shut-off valve in line with the mixer-valve, between the cold-blast and hot-blast lines, is desirable from a safety standpoint to prevent fires in cold-blast lines from "kick backs." There are various types of these valves in use that have given very satisfactory service, and add to the safety of blast-furnace operation.

This short paper gives a brief summary of modern blast-furnace stove development, and I hope the discussion will bring out further points of interest. I should have liked to go into this subject in detail to the extent its importance merits, but did not have sufficient time in the short period allowed for preparing the paper. However, valuable data on stove tests, construction of stove shells, brickwork, etc., written by many blast-furnace operators, can be obtained by referring to the *Journal of the Iron and Steel Institute*, and other technical literature. All this paper attempts to do is to bring out, as briefly as possible, the latest trend of development in this important field.

DISCUSSION

MR. J. C. BARRETT:* I, too, am much interested in both these subjects—the lines of blast-furnaces, and stoves and their equipment. I don't know that I can add anything to what Mr. Maccoun has said on his subject, and I didn't get the whole of Mr. McKee's paper.

The matter of stoves and equipment for good work must, of course, be based on good gas. We have in the past had what we thought were washers, but I don't think we can get very good results unless we get washers that will do better washing than heretofore.

I do not believe you have as good a gas for your stoves as you should have if you do not get less than one-quarter grain of dust in it. Some of you have had washed gas, so called, but it is not properly washed, and I think there might be much better results than we have had. I believe there is now a method of washing that is an improvement, about which Mr. Maccoun could give us some pointers.

The carrying of 1400 degrees is in the right line. A heating surface of 360,000 square feet in a furnace seems to me a pretty big step from where we have been able to operate with clean gas at 1100 or 1200 degrees on a heating surface of 175,000 to 180,000 square feet. It seems to me you have about doubled the heating surface. An additional 200 degrees is a point on which I believe some may differ, and one which may be a subject for discussion.

In regard to central control for stove operation, I think Mr. Maccoun might have included discussion of a regulator—one such as is now in existence, where if you set at 1300 or 1400 degrees your regulator will keep the temperature at that point, without the use of a hot-blast man to regulate the mixer.

It is the aim, I think, of all good furnace men to get as much as they can out of their raw materials to make a ton of iron, and conserve all possible heat units that are developed, which is the goal we are trying to reach.

MR. A. J. BOYNTON:† I wish to express my pleasure at hearing the papers that have been read. In commenting on Mr. Maccoun's very excellent paper, I believe it might be well to consider it for a

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†Vice-President, H. A. Brassert & Co., Chicago.

moment in the same light of past experience with which Mr. McKee has considered the blast-furnace.

In my opinion, many of the circumstances surrounding the construction and operation of hot-blast stoves are based on past history rather than on present conditions and possibilities. The practice of building four stoves for a furnace was undoubtedly dictated in large measure by difficulties with unwashed gas which involved frequent cleaning and partial renewals. With a stove equipment in which the number and size of units were dictated by these conditions, no necessity existed for introducing into the stove a quantity of gas commensurate with the carrying on of the regenerative process as otherwise practiced, and the usual procedure was to occupy three times as long in heating the stoves as was required to cool them. The necessity of building four stoves resulted in a size of stove smaller than made desirable by the requirements of a regenerative apparatus during the cooling phase. From the standpoint of heat exchange and thermal economy there is no question but that regeneration in hot-blast stoves is most advantageously practiced with two sets of apparatus, as is commonly done in the open-hearth furnace and in other applications; nor that the logical development of heating air for blast-furnaces is with two stoves.

The means of introducing gas to the stoves, which Mr. Maccoun has described (comprising regulation of air for combustion, in some cases with both air and gas under pressure) enables a larger volume of gas to be burned in the stove per unit of time than was formerly possible, and makes it perfectly feasible to obtain the same condition as exists in other regenerators wherein the time required to heat up is the same as the time required to cool off. That is the aim that should govern stove design.

The risk of shutting down the whole blast-furnace unit on account of failure of a stove requires that for the present three stoves should continue to be built; probably somewhat smaller than would be desirable if two were considered sufficient In the meantime, however, the problem before the designers of blast-furnace equipment is to construct a stove for use with washed gas with such degree of permanence as will in the light of experience justify the future construction consisting of two stoves without undue risk. It is entirely practicable to build stoves of such size, and the resultant economies will

include a lower installation cost and a much better thermal economy than is now obtained.

Bearing on the practicability of so building stoves that the risk of failure is practically confined to the cold-blast and hot-blast valves, I would cite an experience at the Lorain works. In the year 1907, eight two-pass stoves, which had been constructed with the desire to obtain as great an amount of heating surface as possible rather than a sturdy construction, were completely relined. In carrying out this relining the ring-walls of the stoves were cut to suit the shape of the checkers where they abutted against the walls, and the checker construction at this point included checker tile laid against the wall so that the checker construction was complete and free to slide as a unit against the circular wall. Some ten years later I conceived the idea of increasing the heating surfaces of these stoves by the insertion of diagonal checkers within the square openings, the diagonal checkers being pointed at the ends in the same way that the old Foote checker was shaped. These diagonal checkers rested upon the bearing checkers, the orifices in which were of less diameter than the diameter of the checkers above. After some small-scale experimentation, diagonal checkers were applied to these eight stoves. The condition of the brickwork was so good that we succeeded in using a total of 95 per cent. of the calculated maximum of diagonal checkers. This experience is submitted as evidence of the possibility of mechanical construction with regard to which nothing need be apprehended during a furnace campaign. Undoubtedly this method of construction is in use in other places, but in still others it has not been used, and there have come to my observation cases where stoves have failed on account, as I think, of improper backing of the checkers against the thrust of the brick. Many people are having their brick ground to size, and I believe this is wise. The potential life of a stove lining is so great, and the relative cost so small, that the best possible mechanical design and workmanship are a means to pronounced economy.

I am looking for the time to come in a comparatively short number of years when it will be discovered that the experience with existing installations has been such that it is practicable to discard the third and fourth stoves now in use, after which the two-stove construction will become standard.

MR. J. S. UNGER, *Chairman*:* Will not the construction of the stoves require too great a height for safety in brick construction?

MR. A. J. BOYNTON: With regard to this, I would say that stoves practically 120 feet high have been in service for many years at the Ohio works of the Carnegie Steel Company. I believe that Mr. Barrett will give us his experience with regard to stoves of this height.

MR. J. C. BARRETT: Some of our stoves have been in service for 25 years, and we are relining them now. The height of our stoves is 118 feet and we have no difficulty except as to age.

MR. L. A. TOUZALIN:† While it has been done at Joliet, I don't know that the results after five years would warrant my saying it is good practice. I refer to the four-pass stove known as the Larimer stove. The difficulty we have with that stove is to maintain the division wall at the top, which is subject to much more heat on one side than the other. We have tried various refractory cements, but the design is such that there is an uneven force due to contraction and expansion, which ruptures the wall.

The nearest approach to this is the large two-pass stove at the South works, which I believe is very satisfactory. My only objection to two-stove operation is the fact that at some time during the campaign one stove usually needs repairs of some kind. Taking off one stove under such conditions would, of course, have a serious effect on the maintenance of your blast heat.

MR. JULIAN KENNEDY, JR.:‡ I am afraid I can not add much to the discussion that has been given. In regard to checkers, there is a point where there can be too many flues or checkers for the volume of gas going through the stove. In that case, if you put brick over some of the checkers you will get better results and more efficiency out of the same stove, with less heating surface. I think the tendency is towards larger chimney outfits and larger inlets into the stove, so that all the loss of draft will be taken up in the checker and not through the openings.

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†Superintendent of Blast-Furnaces, Illinois Steel Co., Joliet, Ill.
‡With Julian Kennedy, Engineer, Pittsburgh.

Mr. T. J. McLoughlin:* The trend in recent years in the design and operation of blast-furnace stoves has been to eliminate all but the two-pass type. Investigation has shown that this type of stove gives increased efficiency and decreased operating cost, and for the same results is smaller, simpler and more readily accessible for quick repairs. With the increasing cost of coal the efficient use of blast-furnace gas in stoves and engines, with the consequent increase in surplus gas for utilization under boilers, materially assists in decreasing the cost of pig-iron by increasing the credits for steam generated by blast-furnace gas.

A few years ago, tests made on stoves by sucking air at low velocity and measuring the velocity with an anemometer showed in one case that 47 per cent. of the checker openings were ineffective, 18 per cent. having a negative velocity and 29 per cent. a zero velocity. In another case 56 per cent. of the checker openings were of no use, 46 per cent. having a negative velocity and 10 per cent. a zero velocity. That these test measurements, although made at a low velocity and at atmospheric temperature and pressure, revealed a condition which prevailed even under the normal operating pressure and temperature conditions was borne out by the fact that when the ineffective checkers were blocked off the maximum blast temperature obtainable was increased from 100 to 200 degrees.

Little information is available on the efficiency of blast-furnace stoves, and this is due to the fact that accurate measurement of the pulsating flow from a reciprocating blowing-engine is extremely difficult to make. By the use of turbo-blowers this difficulty is removed, and, since numerous turbo-blower installations are now being made, the next few years will no doubt yield an increasing amount of data on actual stove efficiencies.

The recent tendency toward large hearths and increased volume and temperatures of blast has brought about a lively discussion as to the design of stoves for this condition. The volume of the combustion chamber, the type of checkers, and the area of individual checker openings have been carefully considered. The use of pressure burners, automatic regulation of both gas and air, and more effective insulation will bring the efficiencies of blast-furnace stoves to a higher average.

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Ten years ago the stove efficiencies were of the order of 50 per cent. with stack temperatures of from 700 to 1000 degrees, and 42,000 to 46,000 cubic feet of wind. To-day, the heat balance of an efficient stove shows 75 per cent. of the heat absorbed by the blast with 55,000 cubic feet of blast and a stack temperature of 400 to 450 degrees. The stoves of to-morrow (and some are now under construction) have from 350,000 to 400,000 square feet of heating surface per furnace (four stoves), are equipped with pressure burners with automatic control of both gas and air, are insulated to give a radiation loss of not over eight per cent., and can heat 60,000 cubic feet of air per minute to a straight line heat of 1400 degrees at an efficiency of 80 per cent.

Mr. Arthur G. McKee:* I am afraid I can add nothing of any material value in regard to this subject of stoves, as it is a matter of close personal observation of the stove performance, which I have never had. However, I think it may be said that stove construction, design, installation, and these other matters have been given much better attention in the past few years, and we are certainly getting much better results.

One subject mentioned is that of blocking off the checkers. That is interesting, but should not be a matter of importance, because a stove should be designed so as to prevent any such considerable irregularity of the distribution of air and gas. Is it not true that the gas and air should regulate themselves more or less through these openings? In other words, if there is a flue through which the gas goes down in large volume, that flue should get hot. There should be a draft resistance against its going through that flue, and the gas volume in that flue should be lighter, whereas another flue some place near would be cold and the air and gas in that should be heavy and tend to go down much more readily. In this way you should get an automatic regulation so as to get the same temperature through it all as the gas goes down, and the same is true as the air goes up. In the hot flue the air should go up by its own draft as well as by the pressure back of it, and cool it off through the hot flue; whereas, the air in the cold flue is heavier and goes less readily and should tend to cool less within the flue, and let it gradually build up in temperature.

*President, Arthur G. McKee & Co., Cleveland.

These things are technical and theoretical possibly, but they ought to be considered. I think a stove that is well designed should not have this trouble to any serious extent.

MR. W. MATHESIUS:* I am inclined to be with Mr. McKee on that point. It has come to my attention in the three-pass stove that the rate of heating was very poor, because the conditions during the heating period, as well as during the blowing period, were just the opposite of those that would tend to the automatic heat regulation in the different passes.

I had occasion last summer in a trip to Europe to visit a good many blast-furnaces, and saw there a very decided tendency towards a type of stove construction and operation different from what we seem to consider as modern here. Two-stove practice is now by no means confined to tests. I saw a number of plants where it was in successful operation. They were using a very much smaller checker opening and very much smaller brick dimensions than we do here. I saw a good many openings of 2½ to 3 inches and brick one inch in thickness. In other words, to-day they go a good deal further in expending effort and labor towards catching the elusive calories in the stove practice. In the operation of any of these stoves, it is, of course, absolutely essential to use clean gas, with the same degree of cleanliness as for gas-engine operation. That seemed to be accepted as a settled fact.

I have been trying to ascertain whether they are right and we are wrong, and, if so, what is the reason for the discrepancy. It occurs to me that the answer will be found in the relation existing in these European countries between the value of a ton of coal and the basic rate of wages per day. Over there we find that a ton of coal is worth two to four times the price of a day's labor; while over here we come pretty close to having a ton of coal equal one day's labor. I am satisfied that we can afford to spend only a much smaller amount of labor for obtaining improvement in thermal economy than they do in Europe.

In one place I saw something that might suggest itself to you as being of interest. They put two stoves in series, but still retained the feature of being able to go back again to the four-stove practice.

*Assistant General Superintendent, Illinois Steel Co., South Chicago, Ill.

They found they got along very well by putting four stoves in two series of two, and on that basis proceeded to go to the two-stove plan in the remodeling of another furnace.

I am not certain that we should not seriously consider the two-stove practice, even though it does involve more expense in the purchase and laying of brick, but am satisfied the question is not a technical one. I am convinced that it is perfectly feasible to operate on that plan, it being merely a matter of financial consideration whether the one system is preferable to the other under our conditions.

MR. C. D. RAWSTORNE:* I want to make a statement showing the wide variation in stoves. At the present time we are building five blast-furnaces. St. Louis has three stoves, 22 by 105 feet, with 270,000 square feet of heating surface. The furnace is 92 feet high, with hearth of 18 feet, 6 inches. The estimated production is 600 tons. The heating surface is 240,000 square feet. These stoves have pressure burners.

At Chicago are four stoves, 25 by 105 feet, with 400,000 square feet of heating surface. They have pressure burners.

There is another furnace at Massillon, Ohio. I am not positive of the heating surface, but perhaps Mr. Wilcox can tell. There are four stoves, 23 by 103 feet, with 320,000 square feet of heating surface. There will be pressure burners in these.

At Johnstown, Pa., there are five stoves, 20 by 100 feet. The furnace is 95 feet high, with a 21-foot hearth. The estimated production is 800 tons.

The furnace at Troy, N. Y., is entirely different, not operating on lake ores. It has a 17-foot hearth, and is 95 feet high. I think the heating surface is about 250,000 square feet. The production hoped for is 600 tons.

I make this statement to show the wide variation in the heating surfaces of the different diameters of stoves, whereas the estimated production is not very far apart.

MR. J. S. UNGER, *Chairman*: I had hoped that the paper would give us more specific information on hot-blast stoves. By that I mean the height, diameter and area of heating surface. You know

*Contracting Engineer, Riter-Conley Mfg. Co., Pittsburgh.

that stoves of the same height and diameter may show a pronounced difference in the heating surface. A point not touched upon was the location of the stack and the irregular work done by the checker flues. In studying the velocities of the gases in the several checker flues of a center-combustion stove I was surprised to find the outer rows of checkers were doing most of the work, the middle rows were neutral as the gases were not in motion, while the first, second and sometimes the third row adjacent to the central-combustion chamber were passing the gases in the opposite direction to those on the outside. To correct this condition the inner rows were blanked off with tiles, and deflecting rings were put in the dome of the stove to force some of the gases to the middle rows. By blanking off about 35 per cent. of the area of checkers, the efficiency of the stove was increased almost 20 per cent. The theory that the hot and cold checkers automatically regulate themselves in service did not work out in practice.

Stoves have been built more than 120 feet high, but it is doubtful if this be good practice, owing to the great height of brickwork, which is expanded and contracted many thousands of times during the life of the stove.

Stove bricks are not as a rule made of the most refractory clays, but of such mixtures as have a lower softening point than the bricks used in the hearth and bosh of a blast-furnace. The modern stove must furnish 1400 degrees F. to the blast; consequently, higher temperatures must be carried in the combustion chamber and the tops of the checkers. We know that fire-brick will sometimes begin to soften at from 300 to 400 degrees F. below their melting point. When the weight of the brickwork on a very high stove (which may be from 75 to 100 pounds per square inch) is applied to the hot brick it will distort or bend out of shape.

The insulation of a stove was not discussed in the paper. I have in mind a poorly constructed side-combustion stove on which all paint is promptly burned off on the combustion side.

Tests made on well constructed stoves have shown such slight increase in the temperature of the shell that insulation would not pay. One operator may use an air-space between the brick lining and steel shell, allowing an occasional brick to extend to the shell to keep the lining in position. Another may provide a packing space, to be filled

with ground slag, or loam and slag, or some ground insulating material.

An examination of a stove after a campaign will show that the insulating material has fallen down in a hard mass to the bottom of the shell, and the space is simply an air-space, which should have been provided at the beginning. If the lining wall be made sufficiently thick, what is the use of insulation? Do we actually receive enough benefit to justify it?

The thing that impresses me at this time is the fact that no one has definitely decided where the attack should be located in the stove. Very few tests have been made to determine whether the position of the stack exercises any pronounced influence. Should the exhaust not go to a central point and from there out to the stack, in order that the distribution of gases in the stove be equalized? Do we not at times believe that the remedy for making a more efficient stove is merely to increase the area of heating surface? Have we not, in most cases, enough of heating surface inefficiently used? From data I have studied and have helped to secure I am inclined to believe that only half the heating surface in the stove is used efficiently.

Mr. A. J. Boynton: I think that the conditions (to which several speakers have referred) of evident partial use of the checker flues with the extreme condition of circulation upward where it is supposed to be downward (cited by Mr. Unger) is due to the fact that on account of the desirability of having a large stove for use during the air-heating phase, and also on account of the habit of building four stoves, the amount of gas burned in each stove is so small in proportion to its size that a complete use of the checker area is not so closely approximated as would be the case if fewer stoves were used and the amount of gas per stove per unit of time bore a better relation to the size of the stove.

Mr. Julian Kennedy:* In regard to the down draft not equalizing, I would say that the down draft has a marked tendency to equalize where the gases are not passing through the stove too rapidly; but, in the case of a central-combustion stove where the gases are passing through the stove very rapidly, they are inclined to follow the

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circle of the dome and pass down the outer flues to a greater extent than any other, this current action of the gases more than counterbalancing the natural tendency of the flues to equalize. If the gas can be distributed evenly over the top of the flues, it will be found that the hot flues will take less gas than the cold ones until they equalize. Many of you have seen stoves of the old Massick & Crookes pattern with the third pass upward on the outside, with ice on one side of the stove and the other so hot you could not put your hand on it. There is no doubt that in the absorption of heat, a down pass for the gas is very much more efficient than an up pass. In the latter, the tendency of the gases is to take to the hot flues and the tendency of the cold air is to take to the cold flues, in some cases rendering the upward pass almost entirely useless.

MR. F. B. THATCHER:* From the foregoing statements regarding the difficulty in maintaining stock-lines in furnaces, I might take this opportunity to say a word regarding our own stock-lines before asking the question which I am about to ask.

Last year we found it necessary to reline both of our furnaces, and upon blowing out the furnaces and opening them up we found the stock-lines to be in perfect condition. From all outward appearances they were as good as the day they were put in, with the exception of the two bottom rows of plates which were below the stock-line. These plates had cracked off at one side and curled out a good deal like fish-scales, all curled out in the same direction around the furnace. We attributed this action to the fact that they were subject to unusual strain because of carrying the filling point above these two rows of plates. These furnaces had been in operation over five years, and from the results we have had with these plates we feel perfectly justified in recommending them for use in any furnace.

Certainly the detrimental effect of the use of scrap in the furnace upon the stock-line, as spoken of by one of the previous speakers, was not apparent on the stock-lines in these furnaces, and we had probably used as much scrap as anyone.

I trust that you will pardon my injecting an operating question into a discussion which has primarily to do with construction; and, if the question seems out of place, or simple, you will attribute it to my

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rather limited experience in connection with furnaces, but there has been a great deal said here to-day regarding the desirability of larger stoves and higher temperatures, and I would like to ask if any of the operators present has had the experience of having more heat than could be used. To make my question more clear, I would say that we have recently installed pressure burners on the stoves of one of our furnaces and have no difficulty in getting 1400 or 1500 degrees blast temperature, and even higher if desired, but we have found difficulty in using as high as 1400 degrees blast temperature inasmuch as the furnace tends to hang when using that high temperature. This may be due to the size of the furnace, as this furnace is comparatively small, about 80 feet high and about 17 feet in hearth. Possibly high heats are more adaptable to larger furnaces than to small ones.

Mr. Julian Kennedy: In regard to large hearths, I feel that with a large hearth more heat can be carried in the blast and the furnace will run more smoothly, other things being equal, than with a small hearth. In many cases a large hearth has not enormously increased the tonnage, but I believe that in every case it has caused smoother running of the furnace and also reduced the amount of dust blown out at the top.

Mr. A. E. Maccoun: Mr. Barrett mentioned 175,000 to 180,000 square feet as being sufficient heating surface for a set of stoves for a large furnace. I have known of large furnaces running on heating surfaces as low as that with pressure burners, but with very high stack temperatures—from 750 to 800 degrees F., which is not economical operation from a thermal standpoint. Mr. Boynton and I did some work along these lines several years ago.

Running on stack temperature as high as that, you cannot figure on losing less than 500 or 600 boiler horse-power, so for economical reasons I suggest 360,000 square feet of heating surface, keeping stack temperature under 500 degrees F., which I think is a reasonable limit not to exceed, even though, as I have stated, this does furnish a small amount of reserve stove capacity.

Dr. Unger seems to have laid a great deal of stress on where the stove stack ought to be, and whether there ought to be one central stack or one for each stove. In some respects a central stack is an advantage, in that it keeps the stack temperature uniform, furnishing

a uniform draft, with the result that the stove will take the gas better as soon as the gas-valve is opened. In other words, the central stack for a group of stoves furnishes a constant draft, and efficient stove operation is not interfered with by the necessity for the stack to heat up when a cold stove is put on gas.

As to gases going down the checkers of the stove, I think Mr. Julian Kennedy, Jr., covered that point very well. We ought to have a larger chimney valve; and, if there is enough area underneath the checkers at the arches, we will get a more uniform distribution through all the checkers of the stove. This condition of uneven distribution, as mentioned by Dr. Unger and as pointed out by Mr. Boynton, is often caused by not putting enough gas through the stove. Pressure burners overcome that condition to a certain extent, because they fill the whole stove with gas; and if, when using the pressure type of burner, the operator finds the stove is heating up too quickly, it can be taken off after being on gas two hours or so, and closed up, and will then be ready for the next run on the furnace. But, while on gas, the best gas-burning efficiency will be obtained by filling the whole checkerwork of the stove with gas, the way it should be filled, and thus work the stove all the time at its maximum capacity; and that is one reason many operators prefer the pressure type of gas-burner.

Regarding the difficulties encountered in the use of high heats, I think they can be overcome. At times we have had trouble in getting the furnaces to carry these higher heats, but I think by keeping after it, and adjusting the constituents of the slags, etc., we will be able to get up to the high heats, provided the lines of the furnace, the distribution, coke quality, and other factors are suitable. I am sure high heats can be used successfully, as I know of several plants where they are being used.

As to stove insulation, I do not exactly agree with Dr. Unger that stoves should not be insulated, because we have made comparative stove tests which prove that better results are obtained from insulated stoves, and I believe insulating material can be obtained that will not go to pieces, as was the case with the material described.

EFFECT OF THE PHYSICAL PROPERTIES OF ORE AND COKE ON THE CAPACITY OF THE BLAST-FURNACE*

By T. L. Joseph,† P. H. Royster† and S. P. Kinney‡

INTRODUCTION

In connection with its work on conservation of natural resources the United States Bureau of Mines has made an attempt to study the fundamental reactions that take place in the interior of the iron blast-furnace. This work has been prosecuted, first, by the construction and observations of reactions taking place in the interior of numerous small experimental furnaces at Minneapolis; and second, by correlating the results obtained in the experimental furnaces with those obtained in full-size furnaces. The work has been augmented by a number of investigations pertaining to the physical properties of coke and ore. These have laid special stress on combustibility, reactivity with carbon monoxid, and the reduction of iron oxids.

Scope. It is the purpose of this paper to point out, in so far as the Bureau's investigations have touched upon the subject, the relations existing between the physical properties of coke and ore and the capacity of the furnace, and correlate with blast-furnace practice some of the results of the Bureau's work.

Review of Previous Investigations on Coke. The Bureau's work on blast-furnace coke started at the Southern Station at Birmingham in 1922, with the object in view of determining the factors which govern the quality of coke. Here a study of the physical properties of a wide variety of cokes was made. These properties were weighed, one with the other, with the object of determining their relative importance and their effect on blast-furnace operation. It was found difficult indeed to point to any one or a number of properties and definitely say that that or these are the properties in blast-furnace coke which have a good or bad effect upon blast-furnace operation, and this or that coke is therefore good or bad.

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Combustion of Coke in the Blast-Furnace Hearth. As difficulty was encountered in obtaining concrete data on the physical properties of coke which could be correlated directly with blast-furnace operation, it was decided to make a study of the size, shape, and extent of

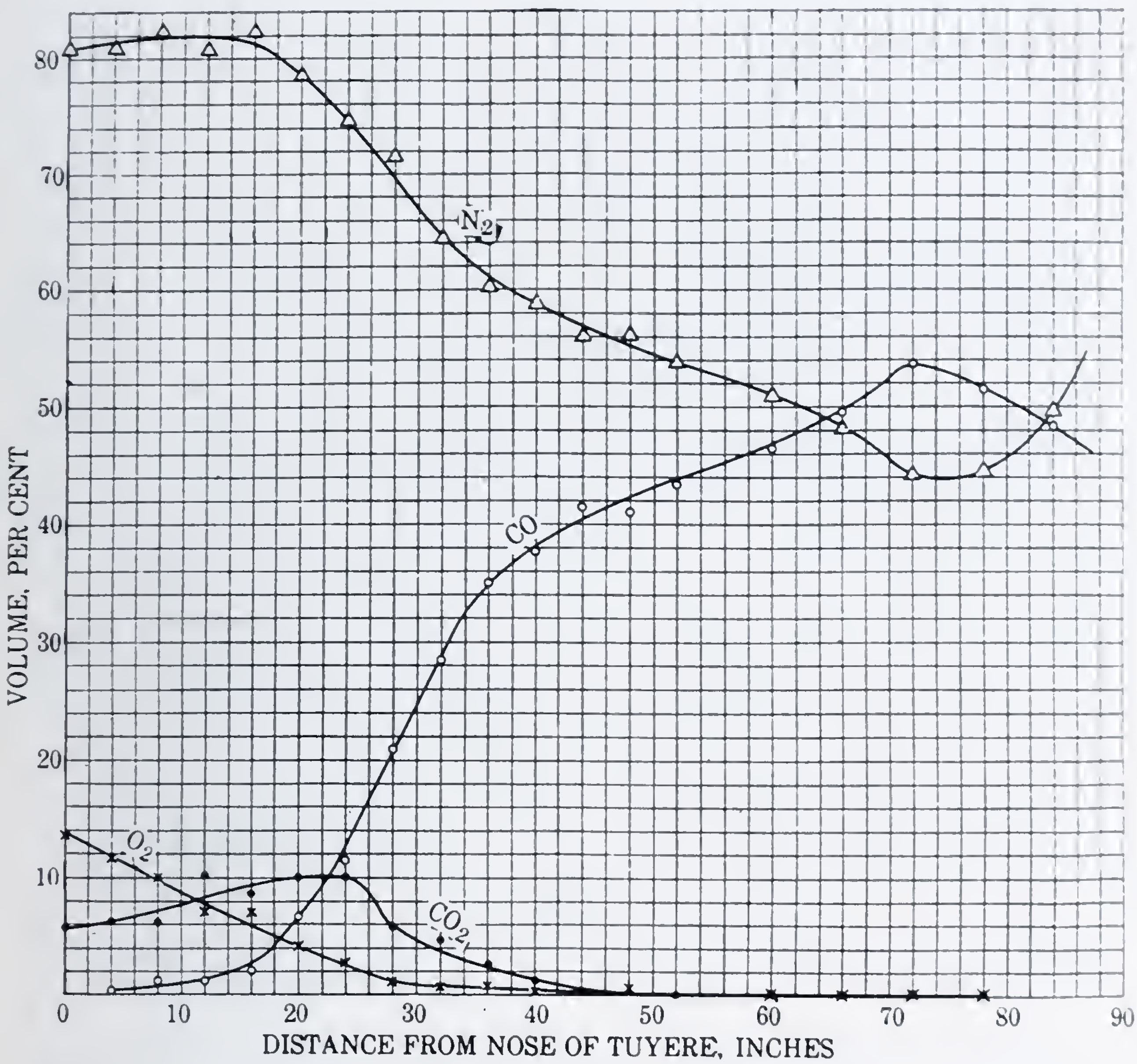


Fig. 1. Tuyere-Gas Analysis. Average of Results from 13 Furnaces.

penetration of the combustion zones at a number of furnaces using cokes of widely varying physical properties. In this investigation Perrott and Kinney[1]* obtained a series of gas samples across the tuyere level from 11 furnaces. A composite curve containing these results and results from two other furnaces by one of the writers[2] is shown in Fig. 1. The curve is characteristic of all furnaces. The results definitely show that the combustion of the coke by the blast is com-

*See references at end of paper.

plete at a distance of 32 to 40 inches from the nose of the tuyere, and this distance is constant regardless of the coke used.

The extent of penetration and relative size of the combustion zones in respect to the area of a hearth with diameter of 14 feet, 6 inches is shown in Fig. 2.

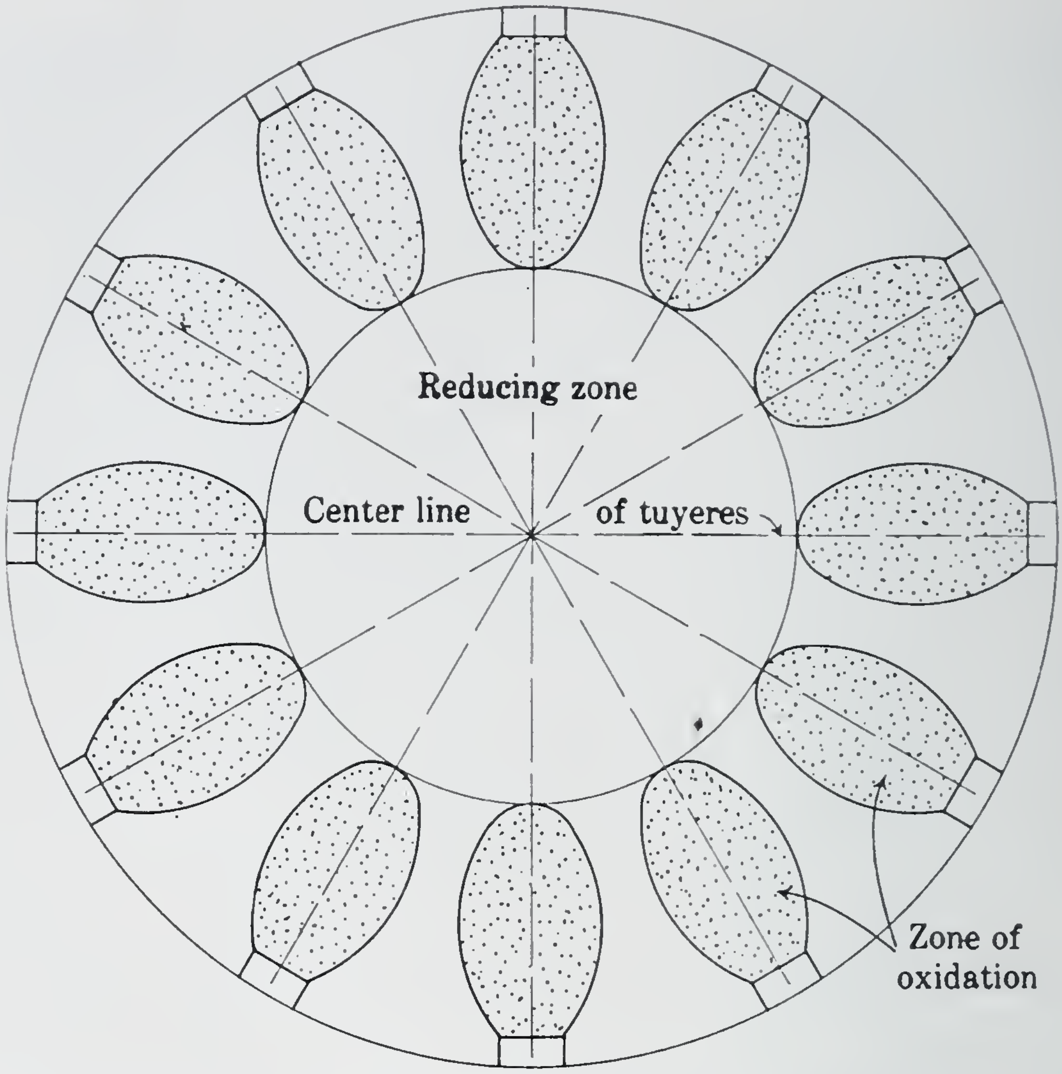


Fig. 2. Diagram Representing Hearth of 14.5-Foot Furnace, Showing Relative Size of Combustion Zone at Nose of Each Tuyere.

During 1924 one of the writers showed by means of gas sampling across a plane 27 inches above the noses of the tuyeres in a full-size furnace that no oxygen existed on this plane, and it was therefore concluded that the vertical diameter or length of the combustion zone was no greater than the horizontal. The detailed results of this investigation are being published.[3] Fig. 3 represents the results of gas sampling on the above-mentioned plane.

Combustibility of Coke. Sherman and Blizard,[4] and later Sherman,[5] determined the combustibility of a number of cokes when using the Kreisinger combustibility furnace[6] shown in Fig. 4. Here the rate of progress of combustion of various cokes was studied with

pieces 1 to 1½ inches in size in 12-inch fuel beds on a grate area of one foot square. The relative combustibilities were determined by the speed of disappearance of oxygen and were calculated for the entire

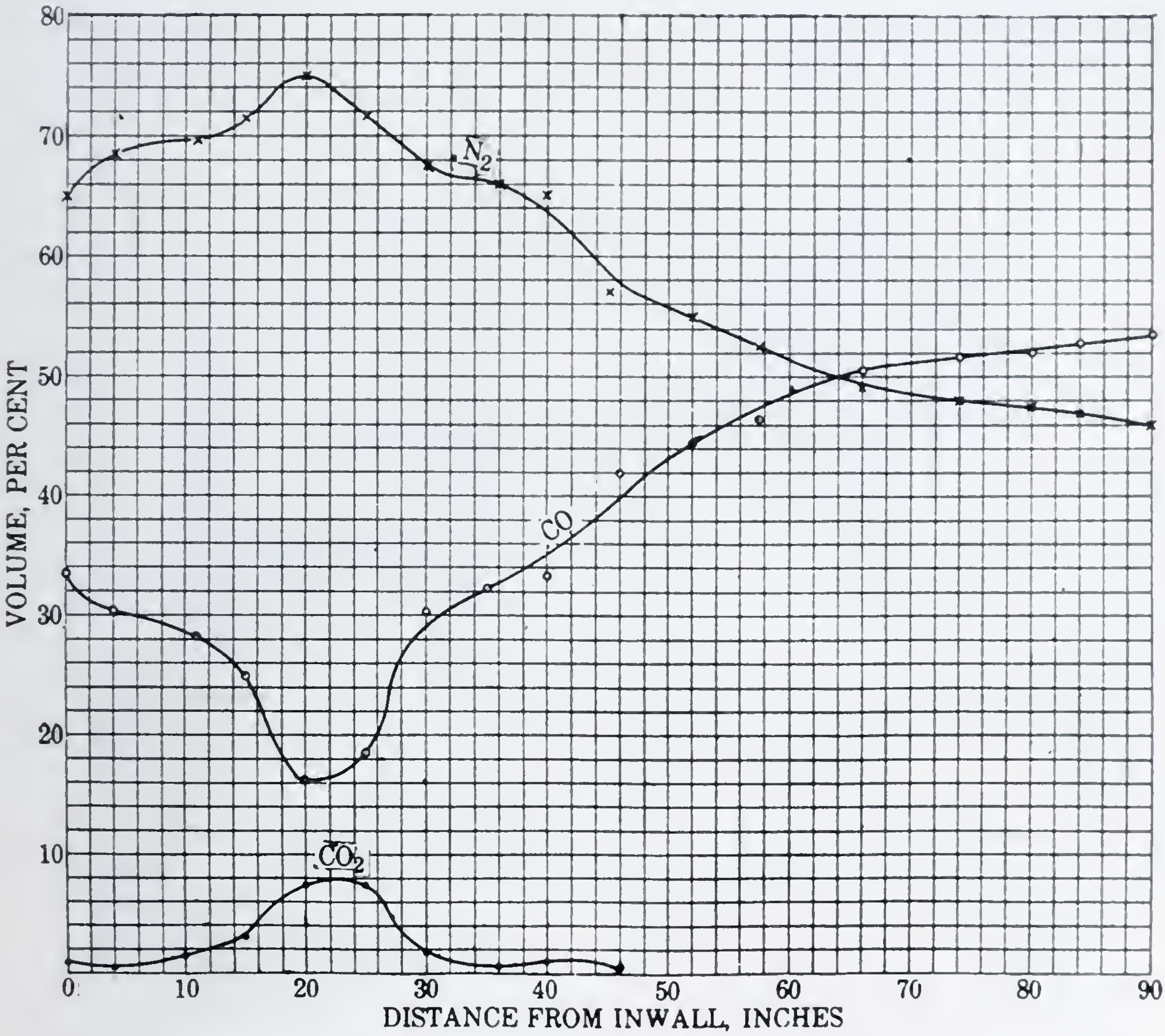


Fig. 3. Result of Gas Sampling in Plane 27 Inches above Center of Tuyeres.

fuel bed by the composition of the gas leaving the bed. The expression $\frac{CO_2 + CO}{2\,CO_2 + CO + 2\,O_2}$ was used for obtaining the ratio of the carbon contained in the gases to the maximum amount attainable. This value was used as a measure of the combustibility. A number of typical results are given in Table I. The results have been plotted in Fig. 5.

Effect of Size of Coke. The results of combustibility tests while using 1 to 1½-inch coke show that there is little difference in combustibility of different cokes. The effect of size is shown in Fig. 6 where 1 to 1½-inch and ⅛ to ½-inch Benham coke was tested. The

curves indicate a shortening of the combustion zone with a decrease in size, which shows that the size of the coke rather than its combustibility has the greatest effect upon the combustion zone.

Kreisinger and Sherman have shown that the length of the combustion zone is not varied by the amount of air blown. Kreisinger varied the air rate from 1 pound to 200 pounds per square foot of hearth area per minute without changing the shape of the combustion zone.

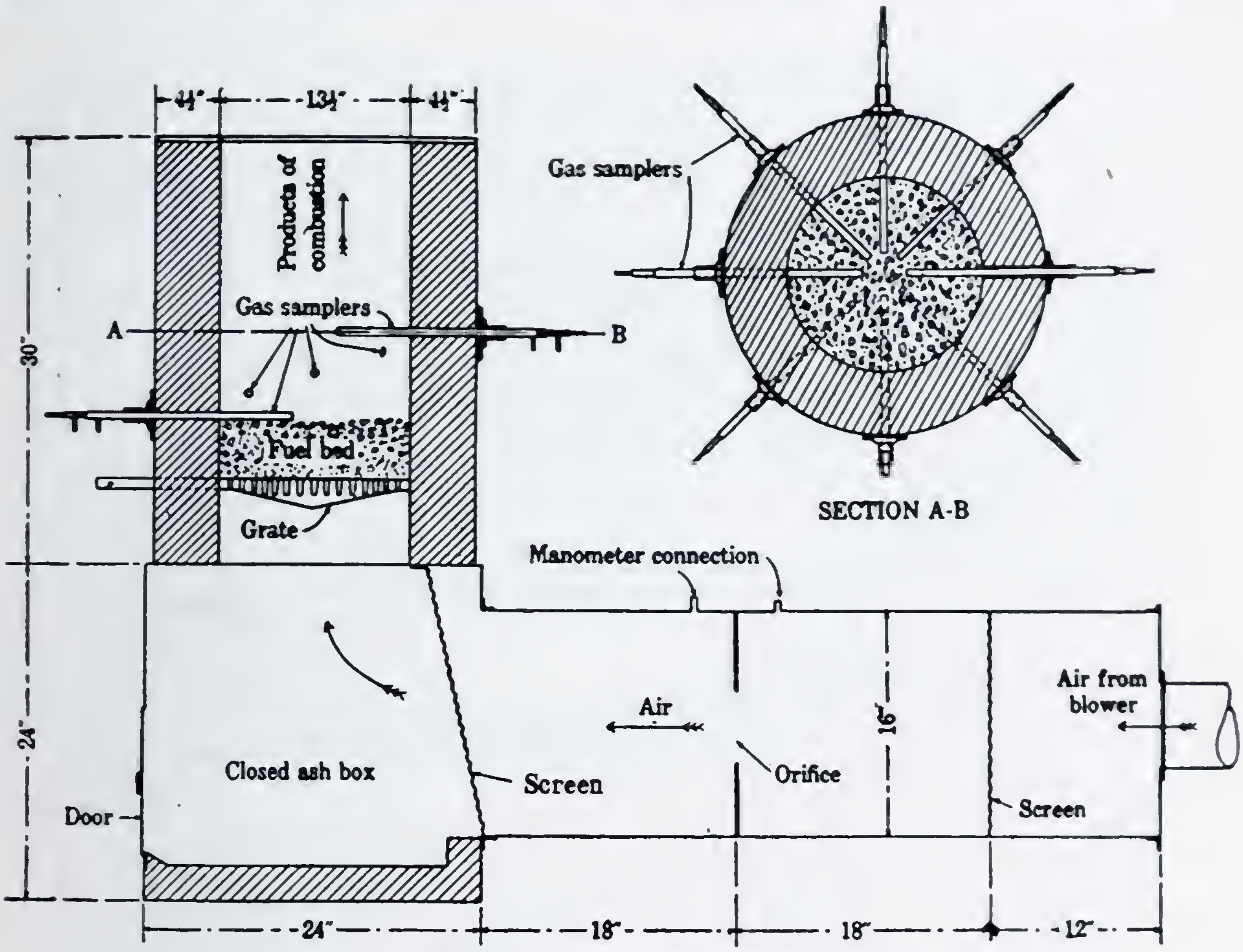
TABLE I. ANALYSES AND PHYSICAL PROPERTIES AND MEAN COMBUSTIBILITY OF COKE

COKE	Analyses, per cent.			
	Benham	Clairton overheated	Clairton underheated	St. Louis
Proximate				
Moisture	0.4	0.1	0.5	1.3
Volatile matter	1.0	0.8	1.7	1.6
Fixed carbon	89.5	87.0	85.4	81.9
Ash	9.1	12.1	12.4	15.2
Ultimate				
Hydrogen	0.5	0.4	0.7	0.7
Carbon	89.0	85.2	83.9	81.2
Nitrogen	0.6	0.7	1.4	0.8
Oxygen	0.2	0.9	0.6	1.1
Sulfur	0.6	0.7	1.0	1.0
Physical properties				
Calorific value, B.t.u.	13,185	12,520	12,535	12,060
Specific gravity:				
Apparent	0.95	1.09	1.03	0.87
True	1.90	1.95	1.97	1.84
Porosity, per cent. by volume of cell space	50.0	44.1	47.7	52.7
Weight, pounds per cubic foot	25.9	30.0	28.6	22.6
Softening temperature of ash, degrees F.	2130	2180	2305	2004
Mean combustibility, per cent.	73	76	77	77

This feature of the coke investigation was correlated by one of the writers[2] with blast-furnace practice at the East and West furnaces of the American Rolling Mill Company, at Columbus, Ohio, where the combustion zones of a furnace were explored by means of gas samples taken in the hearth. One furnace was tested when working

normally at 14 pounds pressure, and then again when the pressure was at one pound. It was found that there was no change in the size or shape of the combustion zone with this change in air volume and tuyere velocity. The results of this work are shown in Fig. 7 and 8.

From these results and the work of Kreisinger and Sherman,[5,6] we predict that a change in velocity due to change of tuyere size will



Sections through experimental furnace.

Fig. 4. Kreisinger Combustibility Furnace.

have but slight effect on the size and shape of the combustion zone, and a variation in tuyere length will simply move the combustion zone in or out with respect to the center of the furnace.

COKE IN RELATION TO FURNACE CAPACITY

In summarizing the foregoing work we may say that Perrott and Kinney showed in 1922 that the combustion zones in all furnaces are of constant length, and Kinney in 1924 showed that the vertical dimension of the combustion zone is no greater than the horizontal. It is therefore concluded that the zones of combustion in all furnaces are practically the same in size and are localized at the noses of the

tuyeres. Sherman and Blizard have shown that there is no marked difference in the combustibility of different cokes; they have also shown that a variation in the size of the coke makes a greater variation in the size and shape of the combustion zone than any of the variations shown by the slight difference in combustibility. Kreisinger has shown that a change in rate in burning has no effect on the

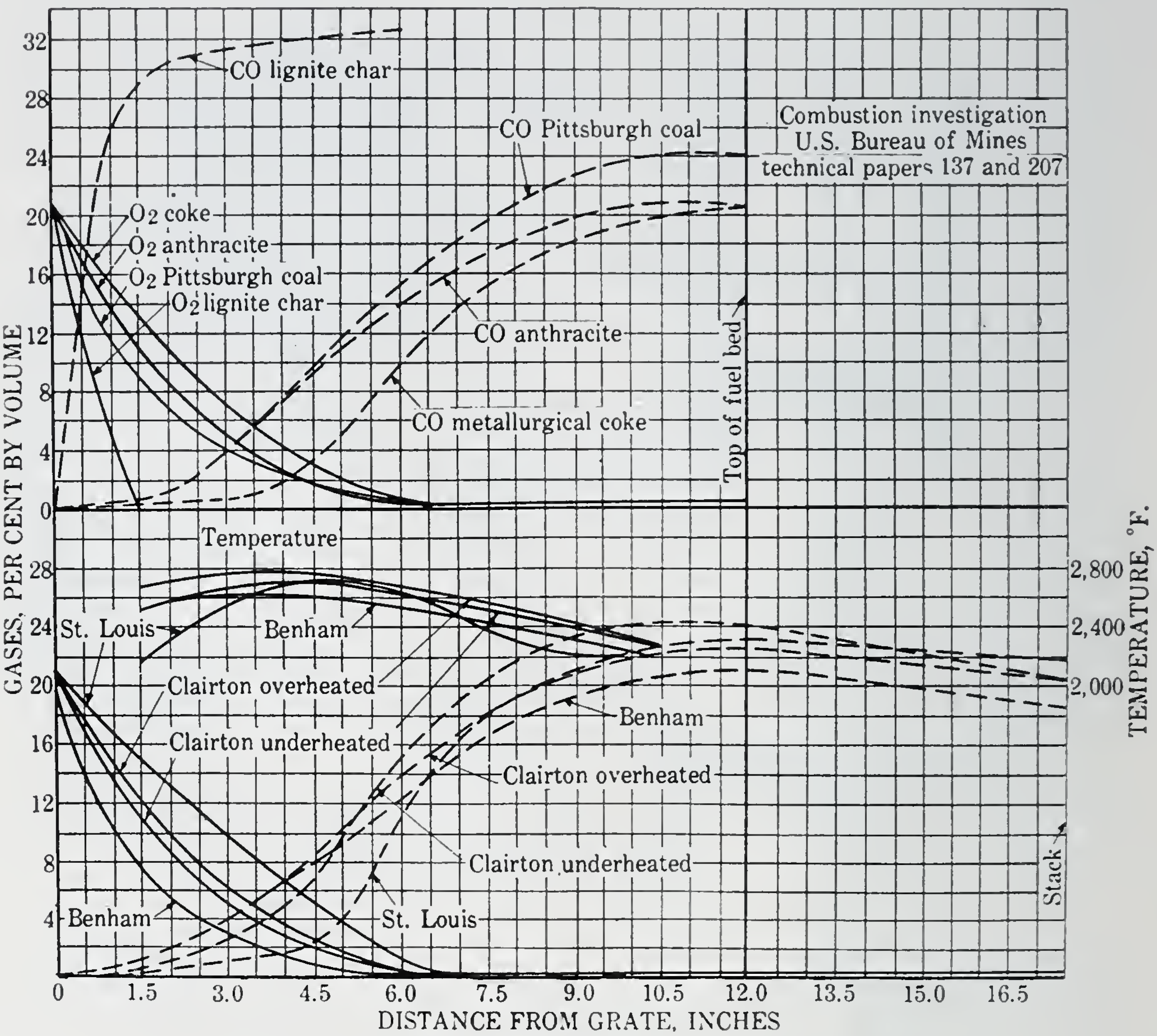


Fig. 5. Combustibility Curves for Various Fuels.

size and shape of the combustion zone; this result has been corroborated in blast-furnace operation. With these data at hand we therefore conclude that the combustibility of the coke shows no marked difference and therefore does not account for the difference shown in blast-furnace operation.

Attention may here be drawn to Fig. 9, which has been plotted from data collected from the 11 furnaces considered in Table II. The apparent density of the coke has been plotted against the quantity

TABLE II. WEIGHT RATE AND VOLUME RATE OF COMBUSTION PER TUYERE

Furnace	Number of tuyeres	Observed wind, cubic feet per minute of dry air at 62° F. and 30 inches of Hg.	Cubic feet per minute	Pounds of carbon per minute *a*	Fixed carbon in coke	Pounds of coke per minute	Apparent density of coke	Cubic feet of coke per minute *b*	Cubic feet of coke per 1000 cubic feet of air	Cubic feet of air per minute per cubic feet of coke
Alabama........1	12	49,500	4,125	54.7	85.6	63.9	0.99	2.07	0.503	1990
Alabama........2	10	25,500	2,550	29.4	82.4	35.7	1.00	1.13	0.44	2258
Alabama........3	16	41,600	2,875	38.1	87.3	43.7	1.14	1.43	0.50	2040
Alabama........4	12	41,700	3,475	46.1	87.2	52.8	1.15	1.71	0.495	2020
Alabama........5	12	40,200	3,500	46.4	86.8	53.4	1.13	1.52	0.435	2300
Alabama........6	12	51,400	4,284	56.8	87.5	64.9	1.13	1.84	0.43	2328
Pennsylvania....1	10	26,000	2,680	35.5	84.7	41.6	1.02	1.31	0.49	2045
Pennsylvania....2	10	41,700	4,170	55.3	85.8	64.5	0.96	2.19	0.53	1900
Pennsylvania....3	15	43,500	2,900	38.4	82.7	46.5	0.98	1.52	0.52	1910
Pennsylvania....4	12	43,200	3,600	47.7	81.3	58.9	1.04	1.82	0.51	1978
Illinois..........1	9	36,000	4,000	53.0	82.3	64.5	0.87	2.38	0.295	1682

a. 75.45 cubic feet of air at 62 degrees F. and 30 inches of mercury are required to burn one pound of carbon.

b. On the basis of 50 per cent. voids in coke.

of air in cubic feet required per cubic foot of coke. Theoretically, the coke consumed is measured by weight, but actually is measured by

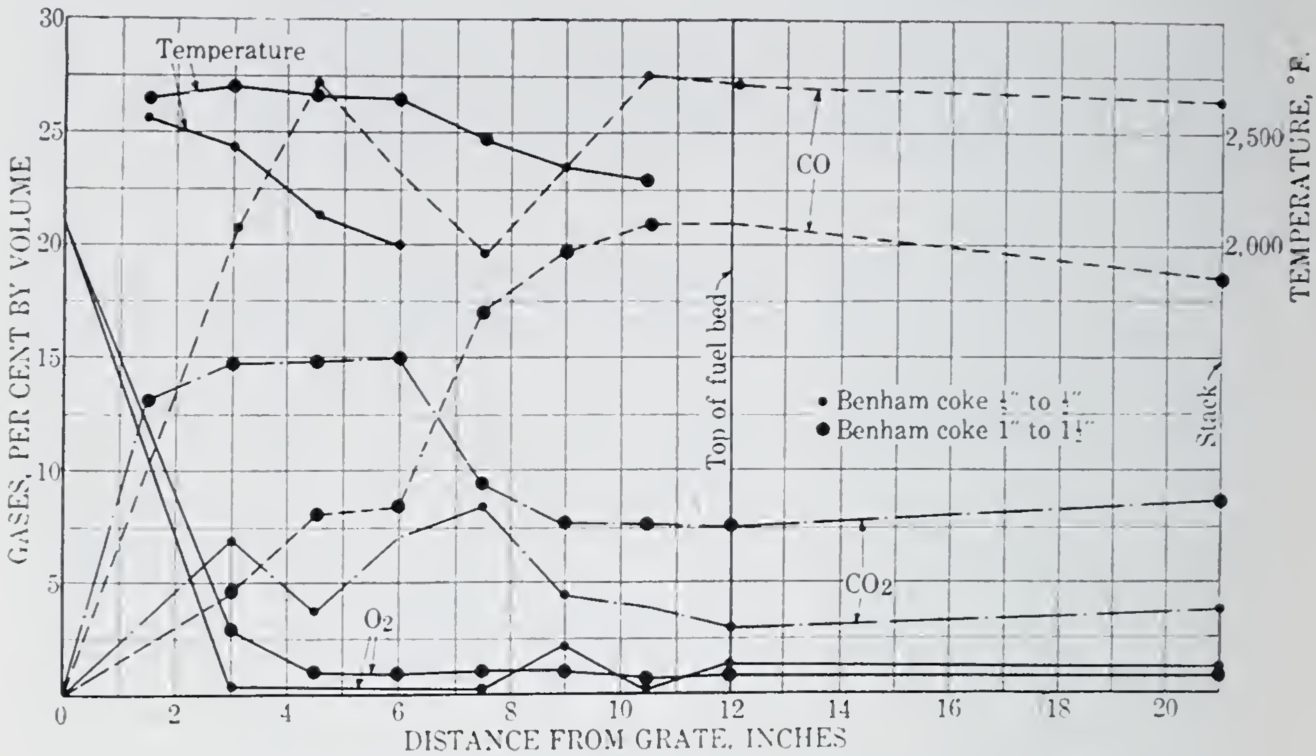


Fig. 6. Effect of Size of Fuel on Combustion in Fuel Bed.

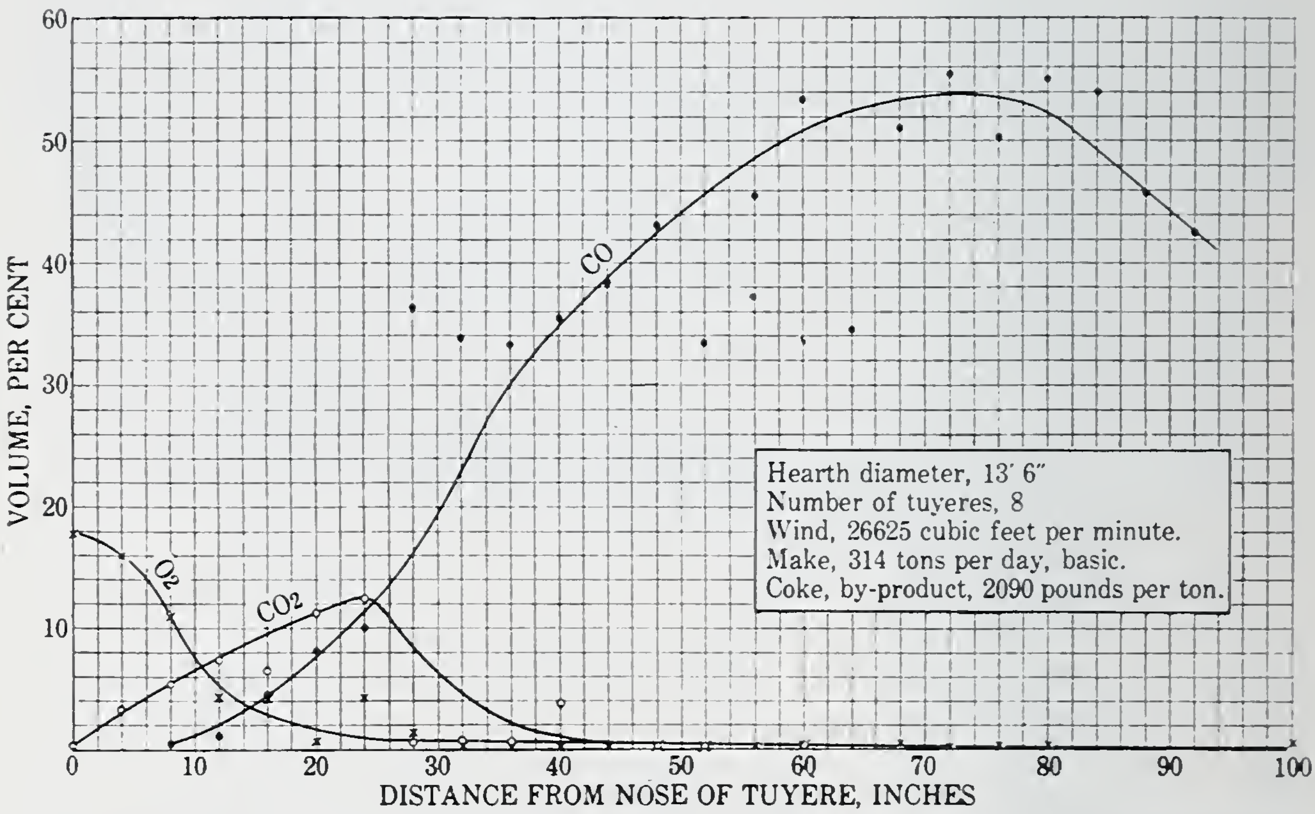


Fig. 7. Results of Gas Samples Taken at Tuyere Level of No. 2 Furnace. Blast Pressure, 14 Pounds.

volume. The rate of driving of the furnace is measured by a stock-line recorder which is a measure of volume. An attempt is made to

hold the density of the coke constant; however, it is possible that this value will vary considerably over a given period. Take, for example, a furnace operating with a coke having an apparent density of 0.9, the curve from data from 11 operating furnaces shows that 1750 cubic feet of air are required per cubic foot of coke. If the density be increased to 1.0, then 1975 cubic feet of air will be required, and 2225

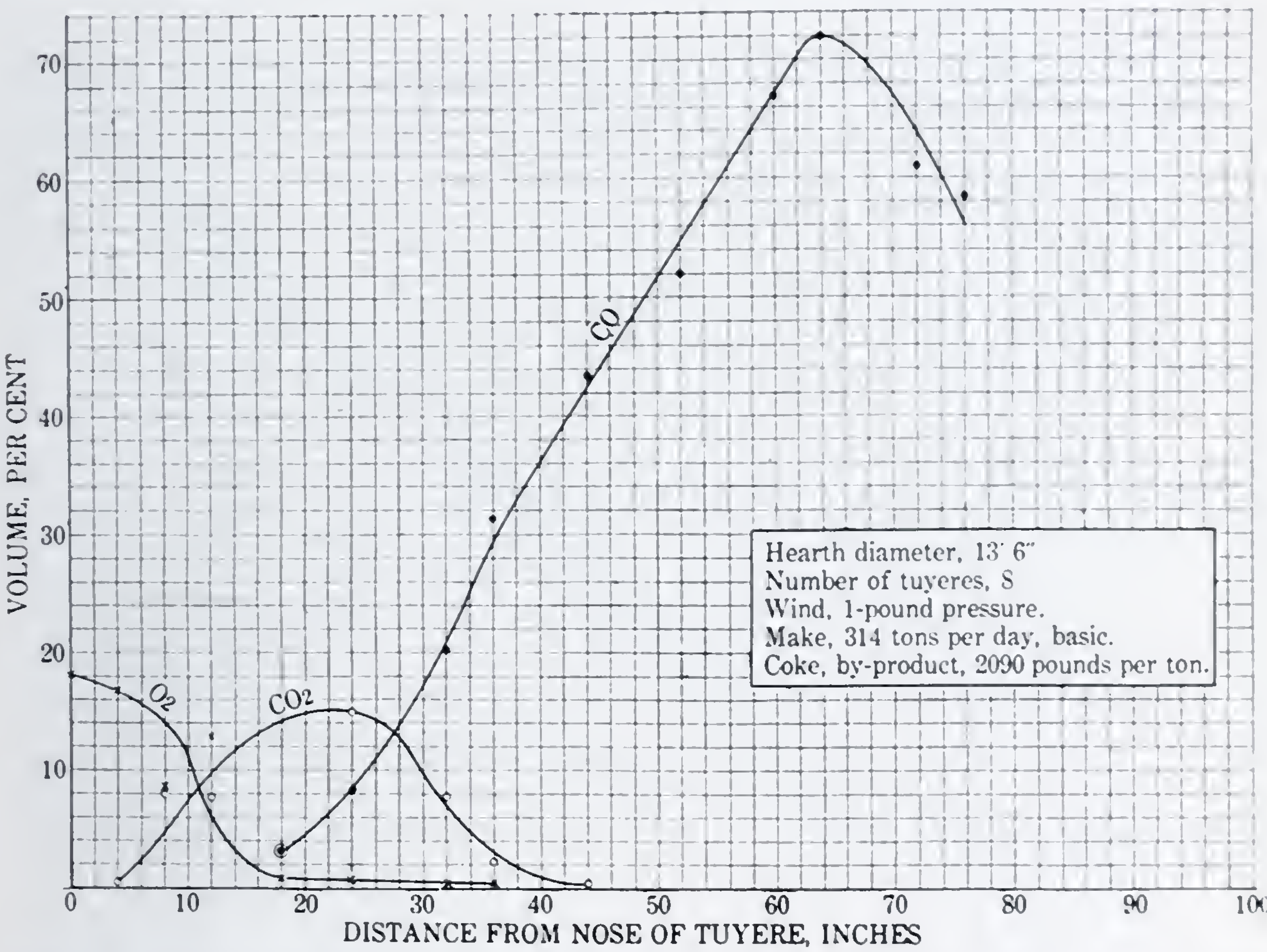


Fig. 8. Results of Gas Samples Taken at Tuyere Level of No. 2 Furnace. Blast Pressure, One Pound.

cubic feet at a density of 1.1. An increase in coke density of 0.2 will increase the air requirements from 1750 to 2225 cubic feet, which is equal to $\frac{475}{1750}$, or 27.2 per cent. The value 27.2 per cent. is slightly high, due to a variation in the fixed-carbon content of the coke used by the various furnaces. If the fixed carbon remains constant, each increase in density of 0.1 will require 200 cubic feet of additional air to burn a cubic foot of coke; that is to say, if it requires 1500 cubic feet of air to burn a cubic foot of coke with a density of 0.9 and fixed carbon of 85 per cent., it will require 2000 cubic feet to burn a cubic foot of coke with a density of 1.0 and fixed carbon of 85 per cent.

This relation is shown in the theoretical curve in Fig. 11. It is obvious that to drive the furnace at the same rate, the wind must be increased, and it therefore follows that the increased wind must be accompanied by an increase in pressure. This increase of pressure is accompanied by an increase in the amount of air lost between the engines and the tuyéres. If the excess air is not supplied the rate of

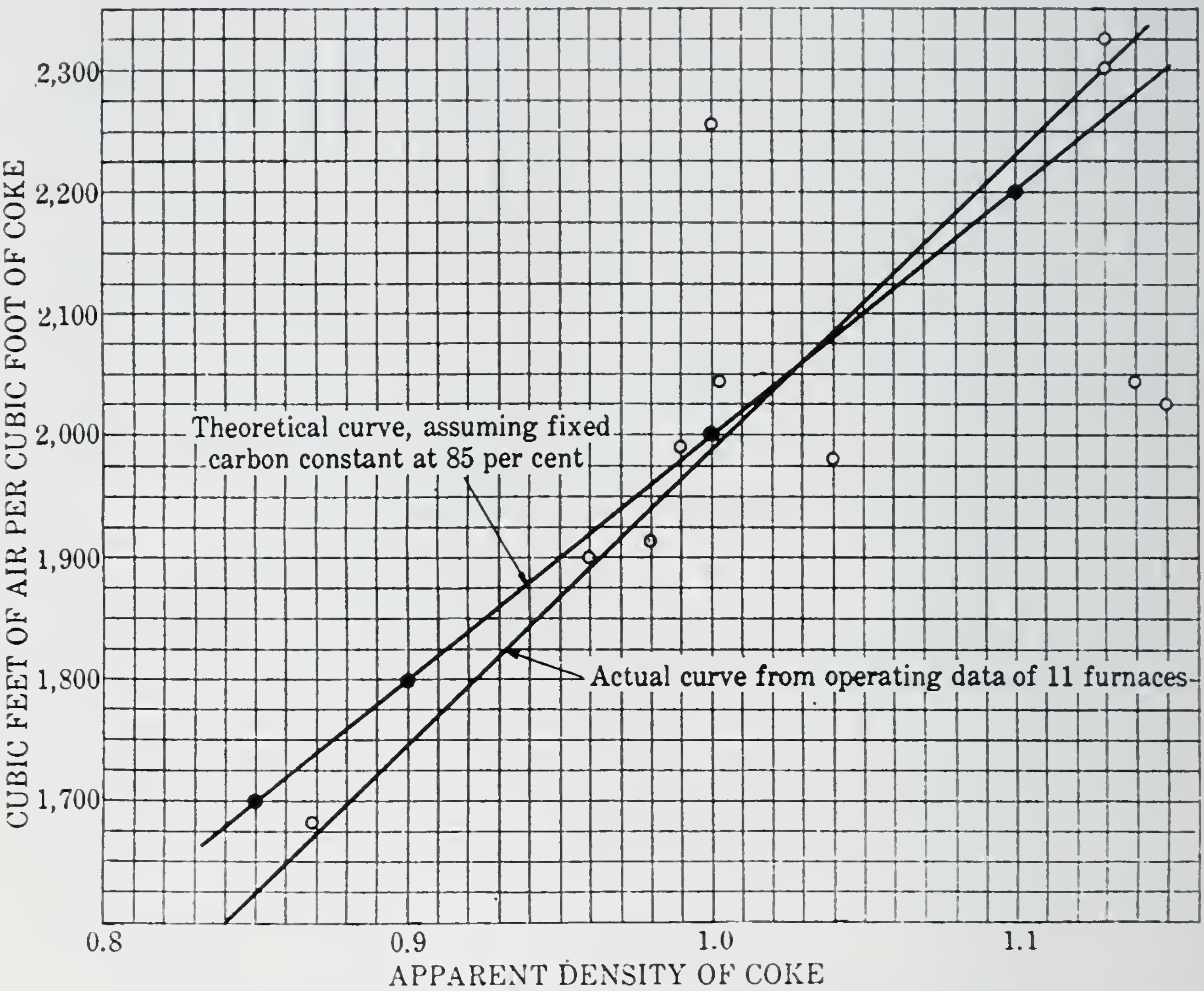


Fig. 9. Relation between Volume of Coke and Air and Apparent Density of Coke.

driving of the furnace will naturally decrease. This brings forth the statement from the operator that the furnace is not taking the wind, and the combustibility of the coke is blamed; whereas, in reality, more wind is needed, but generally it can not be supplied because of the already overtaxed blowing engines. This example is but one of a number which might be pointed out in showing that other factors in furnace operation may have greater effect on capacity than the combustibility of the coke.

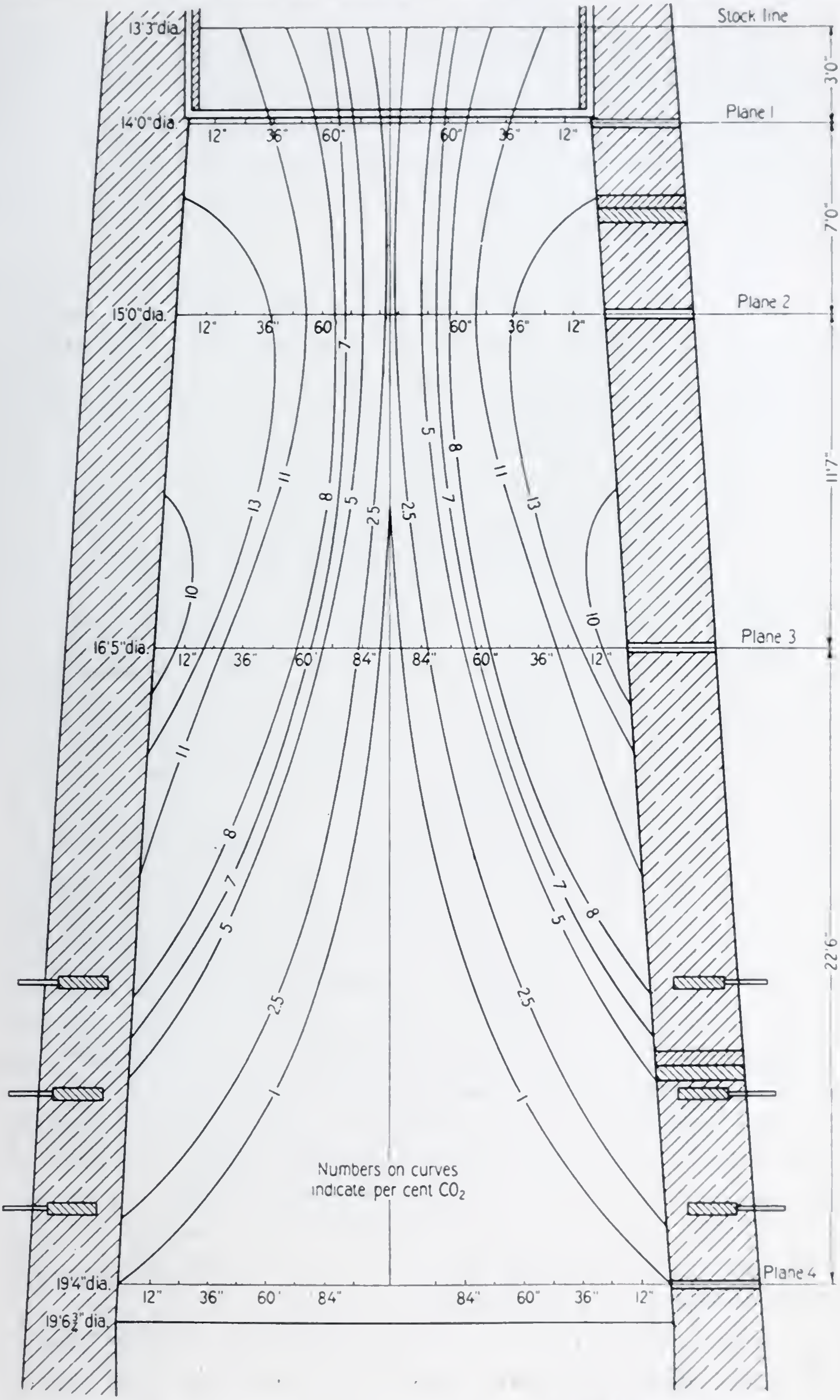


Fig. 10. Section of 300-Ton Furnace, Showing Lines of Equal Carbon Dioxid Content.

Effect of Combustion Zones on Stock Travel. It has been pointed out that the zones of combustion are localized at the noses of the tuyeres (See Fig. 2). As the carbon of the coke is being instantly transferred from the solid to the gaseous phase in the zones, Royster and Joseph[7] have shown that the travel of stock in the shaft of the furnace is toward these tuyeres.

The capacity of the furnace, of course, depends upon the rate of movement of stock toward the tuyere, and this depends upon the rate of gasification of carbon in the combustion zone. The speed of stock descent is in turn dependent upon the time required to effect reduction of iron oxids in the stack. In a study on a full-size blast-furnace, where stock and gas samples were taken across a series of planes between the tuyere level and stock-line, the Bureau of Mines has found (1) that the greater part of the reduction of oxids in the stack of the furnace is taking place directly above the tuyeres, along the line of maximum rate of stock flow; (2) that the flow of the stock in the stack is uneven; and (3) that the maximum stock flow is directly above the tuyeres. The results definitely indicate that the flow of stock and the reduction are not taking place uniformly and that the channels of maximum reduction and flow are directly related to the location of the tuyeres. To illustrate this, two figures are used. Fig. 10 shows lines of equal CO_2 content in the gases in the stack of a full-size furnace with a hearth diameter of 14 feet, 6 inches; and Fig. 11 shows the lines of equal CO_2 content of gases in the stack of the Bureau's experimental furnace at Minneapolis, with a hearth diameter of 30 inches. In the large furnace the high CO_2 is found near the walls, and in the experimental furnace, near the center. The path of the flow of stock and the zones where the maximum reduction is taking place are opposite in the two furnaces, due to the overlapping of the combustion zones in the small furnace and to the distance between the combustion zones in the large furnace. These figures show that gases low in CO_2 content are flowing up through the center in the case of the large furnace and along the wall in the case of the experimental furnace. Gases containing but little CO_2 in the upper part of the stack indicate non-uniformity of reduction and stock flow in the column.

As it is obvious that gases of this character channeling up through the stock column will lower the CO_2 content of the gases and the

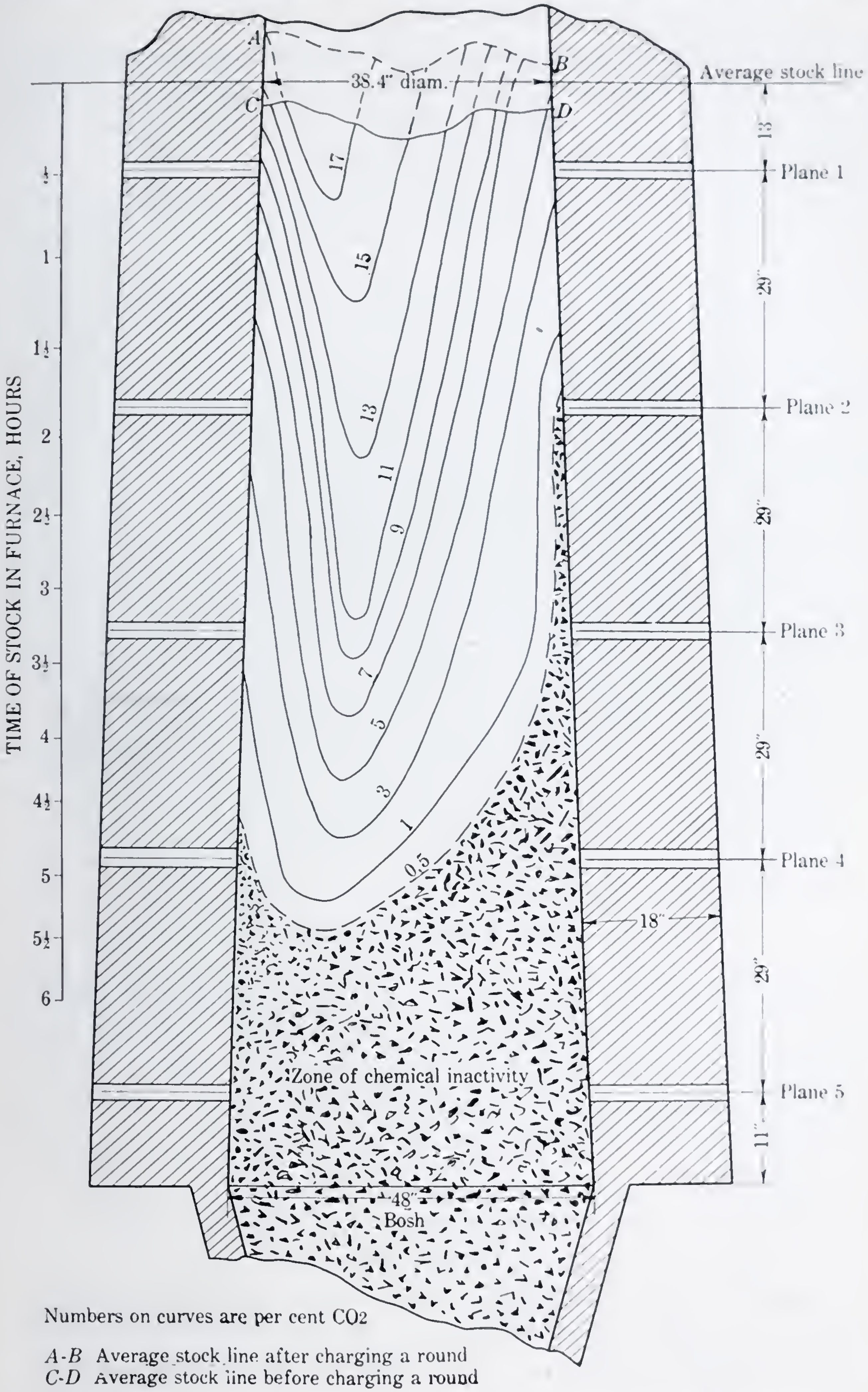


Fig. 11. Carbon Dioxid Gases in Stack of Experimental Furnace.

fuel and reduce efficiency of the furnace, it is therefore natural to suggest that an attempt be made to obtain a more uniform flow of gas and stock in the stack. The ideal condition would be attained if we could obtain uniform stock flow and gas flow in the reducing column. The gases would uniformly increase in CO_2 content as the stock-line is approached, and uniform reduction would take place. The efficiency

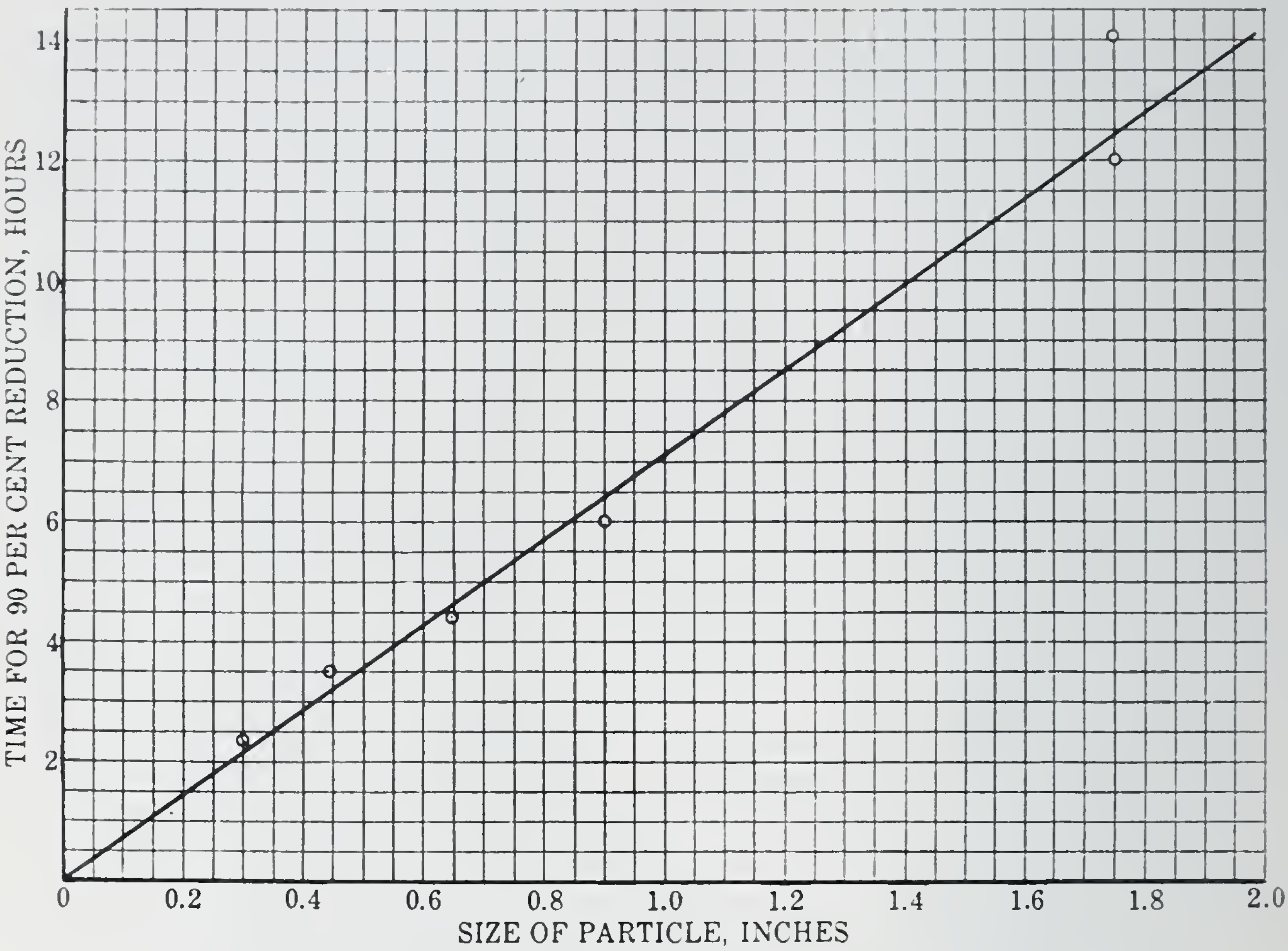


Fig. 12. Relation between Size of Ore and Time of Reduction.

of the furnace would be increased. It is, however, needless to attempt such an ideal condition in an apparatus where the ore is charged from a bell so that it lies in an annular formation in the stack of the furnace, and in an apparatus where the unequal stock movement is accentuated by the gasification of carbon in localized zones at the noses of tuyeres.

RELATION BETWEEN SIZE OF ORE AND CAPACITY OF FURNACE

The Bureau of Mines has found by means of stock and gas sampling on a southern furnace that approximately 85 per cent. of the reduction of the oxids takes place by the time the charge reaches the top of the bosh. This is probably true of any furnace; most of the

oxygen must be removed before the stock enters the bosh. If the rate of driving be increased so that cold, unreduced iron oxids enter the bosh, a cold furnace results. We might postulate, therefore, that a certain amount of oxygen must be removed before the charge enters the bosh; in other words, the rate of driving is limited to the rate of reduction in the stack. Sims,[8] at the Northwest Experiment Station of the Bureau at Seattle, has shown that one factor governing rate of reduction is the size of the ore particles and the type of ore used. In

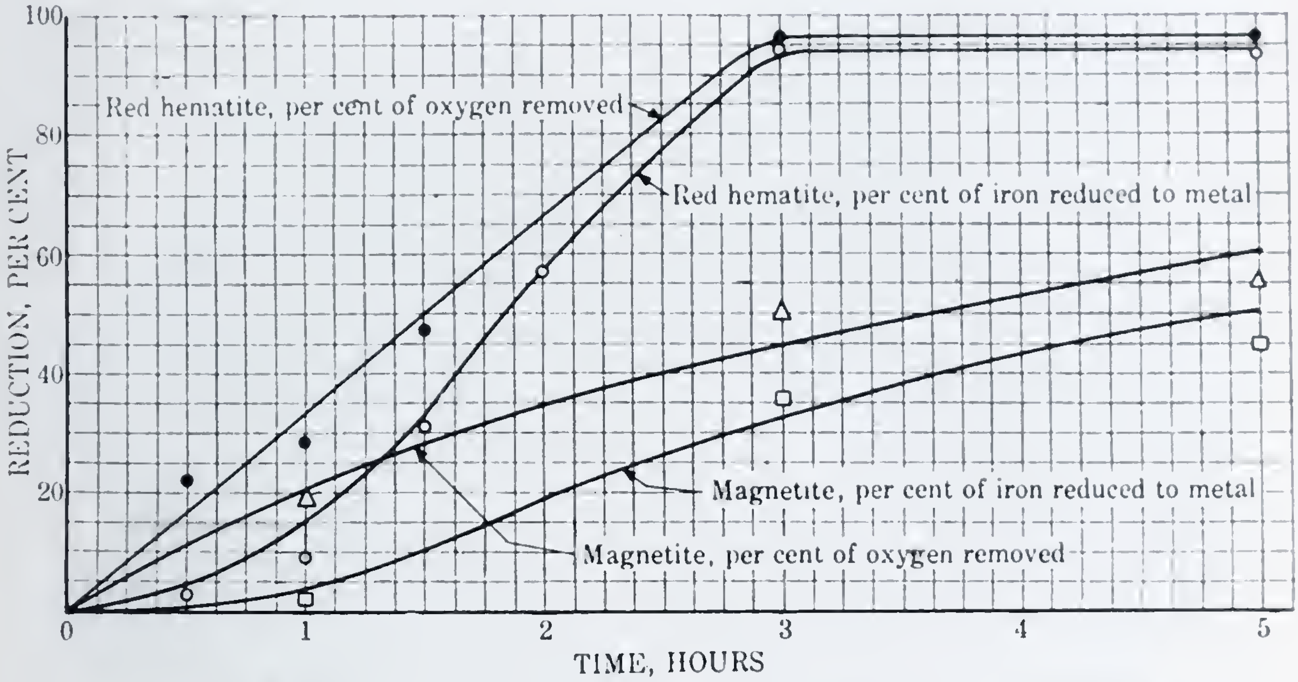


Fig. 13. Relation between Time Required to Reduce Hematite and Magnetite at 900 Degrees C.

this work he used various sizes of rather dense red hematite ore. The ore was placed in the reducing chamber and heated prior to reduction; then a current of heated bosh gas (34 per cent. carbon monoxid and 66 per cent. nitrogen) was passed through the ore column. The tests were run at various temperatures and on various sizes of ore. The results are of considerable interest, as they bring out the effect of size on the time of reduction. A curve (Fig. 12) derived from the results of a great many tests, shows these relations.

Sims has also shown that the time of reduction is not the same for all ores. This is borne out by practical experience of furnace operators, as, for example, the difference in reducibility of hard red hematite ores of the South with the southern brown ore and the magnetite ores. A few comparative results between hematite and magnetite are shown in Fig. 13 for 0.45-inch ores, at a temperature of 900 degrees C.

In Fig. 14 is shown the progress of reduction of iron oxid in a piece of ore. Here a piece of hematite, after exposure to bosh gas, was cut in two. Analysis of the zones for the various forms of iron in the figure indicated that there was present an outside metalized layer (a); an intermediate layer progressing toward the center which is richer in oxygen (b); and a central zone of unaltered ore (c). From the results of this work it was decided that the mechanism of

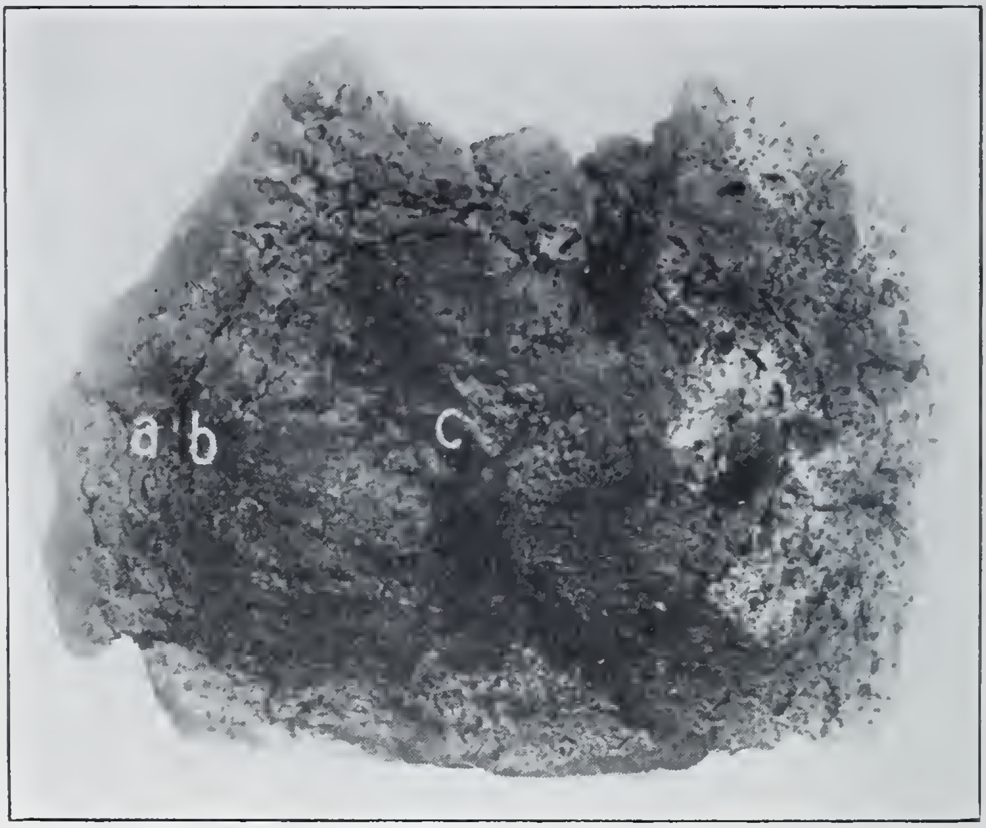


Fig. 14. Section of Hematite, Showing Three Zones.

reduction took place through the checking of the ore and the increased porosity with decrease in oxygen content. The checking is shown in Fig. 15. It was also shown that the overall dimensions of the reduced pieces of iron ore were actually the same after the reduction had taken place, but that during the process of reduction the actual volume decreased more than 50 per cent. This, of course, indicates a decided increase in porosity and accounts for the penetration of the reducing gases.

SUMMARY AND CONCLUSIONS

1. This paper calls attention to the work of the United States Bureau of Mines on the combustibility of coke, and the results point out that there is no marked difference in the combustibility of various cokes.

2. It is shown that the size of the coke has a greater effect on the length or shape of the combustion zone than the small differences in combustibility.

3. It is believed that where coke is charged by volume, changes in density of the coke have an effect on the rate of driving which may often be improperly attributed to the combustibility of the coke.

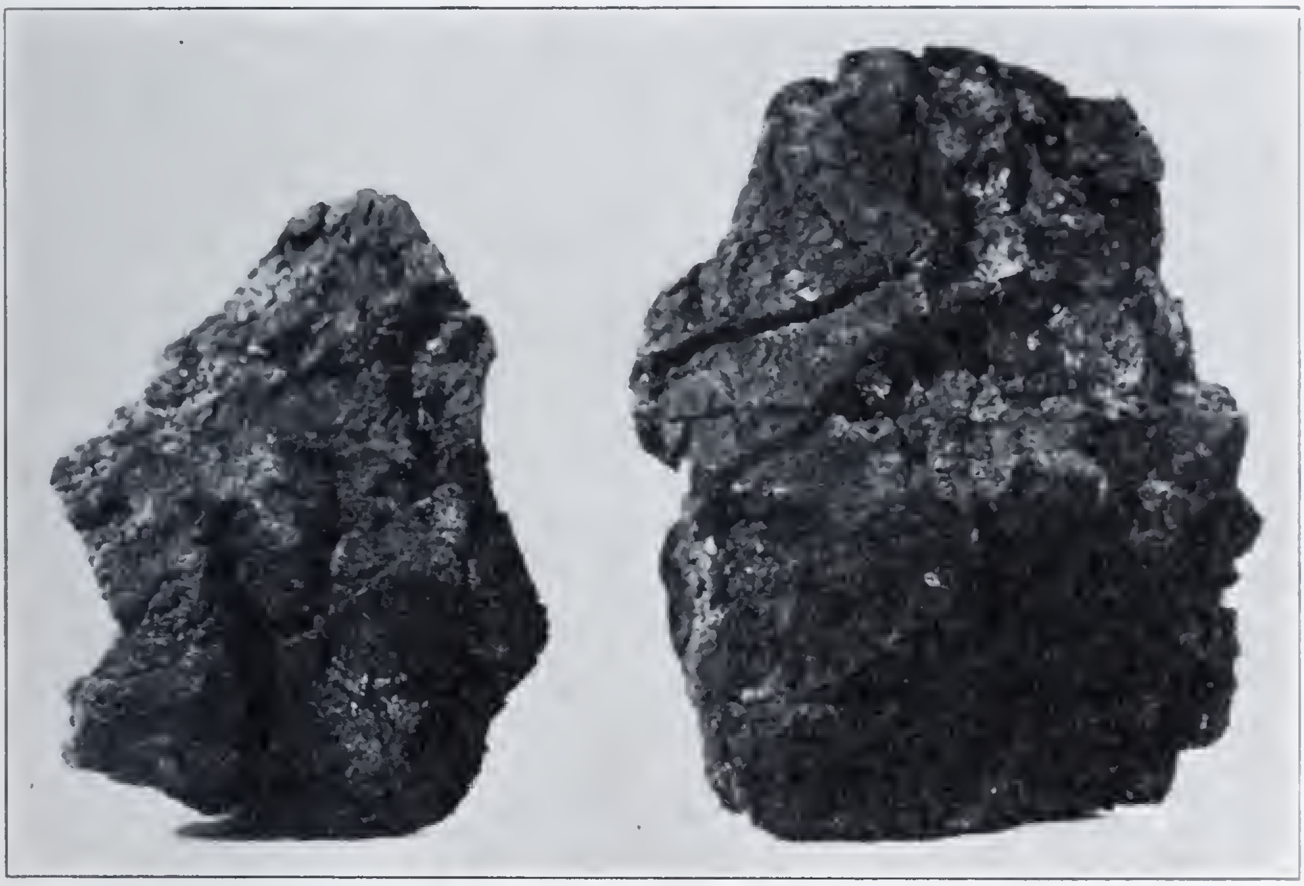


Fig. 15. Sample of Hematite after Exposure to Reducing Atmosphere, Showing Checking of Surface.

4. The writers believe that the capacity of the furnace depends upon the rate of gasification of carbon at the tuyere, but this rate is limited by the speed of reduction in the upper part of the shaft.

5. It is shown by Sims that the rate of reduction is a function of the size of the ore particles.

6. From the work of the Bureau on its experimental furnace and a full-size furnace it is shown that the flow of stock in the shaft is not uniform, and this flow is regulated by the gasification of carbon in the localized zones of combustion at the noses of the tuyeres.

7. It is suggested that the capacity of the furnace may be increased by changes which will permit of better contact between gas and solid.

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DISCUSSION

Mr. J. S. Unger:* I have been interested in what Mr. Joseph says about the influence of the physical properties of coke, ore, and stone in the working of a blast-furnace.

With reference to the size of the coke, I quite agree that size is an important consideration. Some years ago, in trying to find out something regarding the combustion of coke, we made a number of experiments.

We found that when we used coke which passed a 1½-inch screen and remained on a ¾-inch screen the results were erratic, as there was too much difference in the size of the lumps. We were compelled to screen through a 1¼-inch screen and catch on an inch screen before the results would check.

In these experiments the quantity of coke burned had to be considered. When we burned 100-pound samples too many variables were introduced into the work. Until we used 300-pound samples of the same sized lumps and continued the burning period for not less than three hours, we could not get results which were comparable. The results seemed to indicate that all blast-furnace coke should be carefully sized before being used. It was proposed to separate into several sizes, discard the fines passing a ¾-inch screen, and then use the same size of coke for the same charge instead of mixing the several sizes as in regular practice. A study of the proposal showed that additional coke bins were required to take care of the several sizes and the cost of screening had to be considered and the extra cost was not justified.

We operated a blast-furnace on a mixture of regular coke with an equal amount of coke passing a 1½-inch screen and remaining on a ¾-inch screen. The furnace worked very well on this mixture, but, when the fine coke was increased to 70 per cent., the furnace began to slow down, and when operated on 90 per cent. of fine coke it gave trouble within 48 hours and the fine coke had to be taken off.

Another interesting point in Mr. Joseph's paper is that 200 additional cubic feet of air are required to burn a cubic foot of coke with each one-tenth increase in density. This appears to be perfectly logical, as there would be more carbon to burn in the coke of higher density.

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I do not understand why there should be such differences in the gas composition lines between the small and the large furnace, unless it be attributed to some irregularity in the manner of charging. From the illustration one would say that the small furnace was charged from one side.

Regarding the question of the sizing of ores—furnaces operated with Lake Superior fine ores do not appear to give as large tonnages as when operated on lump or semi-lump ores. If the question be put up to the blast-furnace superintendent, I believe he will choose lump ores in preference to fine ores, if he is expected to make a large tonnage. This does not agree with Mr. Joseph's statement that the smaller the lump of ore the faster the reduction. Briquetting or sintering the fine ore improves the furnace production. Do the theoretical conclusions agree with the practical facts?

Mr. A. E. Maccoun:* I doubt whether these curves are what we would actually get in our modern furnaces. For instance, we have a great deal more depression in our stock-line than was shown in the diagram, and I think there is a greater flow of gas up the center of the modern furnace than your sketch would indicate. I base that on an experience I had years ago in using what is known as the Kelleen distributor. At that time we threw to the side as well as to the center—a double distribution, so as to roll towards the walls, and the large stuff rolled towards the center, with two lines of maximum flow of gas up through the stock. We used those distributors very successfully when on a large percentage of Old Range ore and got very good results; but, later on, as the ores became finer and we had to contend with that, we found that the large bell gave us a big hollow in the center and gave much better results than could be obtained with the Kelleen distributors.

Your whole talk is very interesting, but I don't think we ought to pass very many definite conclusions on it, because I feel sure that the flow lines represented by these sketches are not what you would actually get in a blast-furnace. We have made some experiments—probably not to the extent you have—and I think it is a thing that should be given still more research.

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Another thing that I believe has a very marked effect is whether we are working the furnace all the way through at maximum capacity, and whether the furnace is fully filled with gas going through the whole stock of the furnace. True, you can get a furnace working up one or the other side; and not evenly all around, but to get the best results on a test of that kind the whole ought to be working evenly and the distribution as good as can be made, so that the whole result will be comparable to what we actually have in our furnaces. Your results are, however, very interesting and I think you have made a great stride towards determining more about what is going on inside the furnace.

MR. T. L. JOSEPH: Dr. Unger has raised a question about the distribution of the charge in the little furnace. The distribution of the ore in the top was good, but one tuyere had been made larger to study the effect of combustion in the hearth on stock descent. The stock moved to the larger tuyere, which accounts for the lopsided position of the CO_2 curves.

Dr. Unger's results on the sizing of coke are very interesting. I did not intend to advocate sizing of coke, but desired to point out the effect of size upon combustibility. I was merely trying to point out that the absolute size of pieces exerts a marked influence on the size of the combustion zones, and that the way coke burns in the furnace probably affects the way the stock settles.

The data on the relation between ore size and time of reduction was included to show that large pieces of ore reach the hearth unreduced, and have a tendency to chill this part of the furnace where temperature is important. In the case of Mesabi ores, this does not apply to the major part of it, but to oversize pieces which should be crushed before being charged into the furnace. I think the practice of charging large pieces of ore in the blast-furnace is being abandoned.

While it is true that smaller pieces of ore reduce in a shorter time than larger ones, there is a point where the problem of getting gas to flow uniformly through a bed of fine material becomes of greater importance than the question of absolute size. This is a mechanical or physical problem which is very important in the use of Mesabi ores. The relation between size and time of reduction would hold if it were possible to get contact between the ore and the gas

stream. Without this contact no reduction can take place. The finer the ore, the easier the reduction until it becomes difficult to get diffusion of gas through the ore.

Mr. A. E. Maccoun: I do not believe the diagram of flow of the stock corresponds to what we have as to results, for instance, in one of our large furnaces.

Mr. T. L. Joseph: How do you account for the high CO_2 at a position about 36 to 60 inches from the inwall of the furnaces? Those observations, shown in Fig. 10, were taken on a 300-ton furnace. The CO_2 values were high at the position first referred to.

Mr. A. E. Maccoun: That was only a 300-ton furnace? It wasn't an experimental furnace?

Mr. T. L. Joseph: Yes, a 300-ton furnace.

Mr. A. E. Maccoun: But it was comparatively small?

Mr. T. L. Joseph: How would size of furnace affect the CO_2 curves?

Mr. A. E. Maccoun: I think the way you have your stock-line on top is different from what we have. We have a great deal more depression in the center.

Mr. T. L. Joseph: Is the slope of the stock-line in your furnaces steep enough so that your coke and ore roll to the center?

Mr. A. E. Maccoun: Yes, to some extent.

Mr. T. L. Joseph: You would think your coke would roll more than your ore?

Mr. A. E. Maccoun: Yes.

Mr. T. L. Joseph: I can see that such a condition might be the solution to the entire situation. If the charge in the center of the

furnace is open or porous, the gas will flow more freely in this part of the furnace, inasmuch as the resistance is less.

I should like to ask Mr. McKee if there is not some way of preventing the excess flow of gas to the center of the furnace.

MR. ARTHUR G. MCKEE:* I told you about a Kelleen distributor, which put the coarse materials around the walls and in the center. This was used with the Old Range ores with some success; but, with the finer ores, we found we got far better results with the coarse materials in the center and with the bulk of the fines near the wall, as is the result of using a bell four feet less in diameter than the top of the furnace.

MR. W. MATHESIUS:† It has been my privilege on several occasions during recent years to discuss privately with representatives of the United States Bureau of Mines and with others the experimental work executed by the Bureau's investigators which forms the basis for the paper just presented.

I gladly avail myself of the opportunity afforded here, through the courtesy of this Society, to repeat publicly that in my opinion this work deserves the highest praise of every blast-furnace operator. This comment pertains to the selection of the subjects and the scope of the investigations, as well as particularly to the thoroughness and the almost infinite patience which have marked the execution of the experimental program. It is, furthermore, gratifying to note that in most respects the results obtained are not only consistent themselves, but also tend to verify and substantiate the often less comprehensive work of earlier investigators.

I regret that the limited time which I have had at my disposal did not permit the preparation of a more detailed discussion on the various phases of the Bureau's investigations, such as they deserve on account of their scientific interest as well as their practical applications. However, since my remarks in this respect would have been largely affirmative, it seems permissible to confine my comments here to some of the conclusions which in this paper have been drawn from the experimental results and which, in several instances, do not appear to me to be the only interpretations possible.

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†Assistant General Superintendent, Illinois Steel Co., South Chicago, Ill.

Following the order of the topics as given in the authors' "Summary and Conclusions," I should like to point out that the laboratory work of Sherman, Blizard and Kreisinger, and the corresponding investigation in blast-furnace practice by S. P. Kinney, seem to offer conclusive proof that the size and shape of the combustion zone are a direct function of coke combustibility. Whether combustibility is considered in its relation to the physical character of coke pieces of equal size or in relation to a varying range of coke sizes, it may be true that the extent of the variations found would appear small when judged in comparison with the hearth diameter of our commercial furnace stacks.

It seems to me, however, that there is little reason for including in this comparison a vast hearth area which admittedly has no part in the reactions of combustion. Instead, I should prefer to correlate the results of the combustibility tests with the normal extent of the combustion zones in the blast-furnace. If this be done, it appears to me that the different rates of progress of combustion, as determined for various fuels and fuel sizes, may indeed be conceived as having a marked effect on this phase of the reactions in the blast-furnace hearth.

Similarly, I would suggest that the effect of changes in size or length of tuyeres on the combustion zone should not be judged, as it is done by the authors, with reference to its position relative to the furnace center, but rather in regard to its distance from the hearth and bosh walls. If this be done, it appears to me that a logical understanding becomes possible of the marked effect on blast-furnace performance, which, as will be readily conceded by furnace operators, is often realized from a change in length or size of tuyeres.

The third of the authors' conclusions would seem to presuppose that, where coke is charged by volume, furnace operators would judge the rate of driving solely by the number of charges made for a given time and without considering the weight of the coke contained in the charge. This I do not believe to constitute general practice, simply because it would not permit of producing a grade of iron within given specifications which can be maintained only as long as the ratio by weight of the ore burden to the coke is held constant within reasonable limits. I am of the opinion that the weight of the coke charged per day is the more commonly accepted index of the rate of furnace driving, whether such coke be charged in units of weight or of volume,

and this index would seem to be free from the error which the authors suggest as possible.

To me the most interesting phase of the authors' work is referred to in item 6 of the conclusions, which calls attention to the non-uniformity in the descent of the stock column and in the ascent of the furnace gases in the blast-furnace stack. From the facts as determined experimentally—that in their laboratory furnace with a 30-inch hearth the highest CO_2 content was found in the center of the stock column, while on a 300-ton furnace with a hearth diameter of about 14½ feet the highest CO content was found in this section—the conclusion is drawn that the flow of stock and gases is directly regulated by the gasification of carbon in the localized zones of combustion at the tuyeres. This conclusion does not seem to be justified by the experimental data as presented.

Fig. 10 and 11, showing lines of equal CO_2 content, do not clearly illustrate the fact that in the experimental work a zone of practically uniform gas composition over the entire area of the furnace stack was determined. This zone was located approximately at the height of plane 4, Fig. 10, and showed at this level, which is at the lower end of the furnace stack proper, the non-uniformity of gas composition as existing in the hearth and illustrated, for instance, in Fig. 1, had become practically equalized. In other words, at this level the CO_2, CO, and N content of the gases was found to be practically the same throughout the entire cross-sectional area of the furnace stack.

To me this result suggests strongly that, at this furnace level, the directing effect possibly exerted on the gas flow by the individual tuyeres in their immediate vicinity has ceased, and that the distribution and composition of the gases at higher furnace levels is primarily a function of stock distribution. That the latter is affected by the size and shape of the hearth and bosh is of course recognized, and this realization justifies the American type of charging arrangement which deliberately deposits the major portion of the finer burden materials in an annular formation close to the furnace walls. It may well be conceded that with this arrangement the working efficiency of a given stack volume is somewhat lower than would prevail in the theoretical furnace, where the porosity of the stock column would be uniform at every level and at every point of the cross-section; but it will also be

apparent that this ideal is unattainable in practice with a considerable and variable range of material sizes, and that it is preferable to deviate toward the open center rather than the open periphery, because the latter condition would unquestionably entail materially higher charges for stack maintenance.

There are still operating in Europe a number of furnaces where the materials are charged toward the center of the stack and where an open periphery is the result, as it was found to exist in the Bureau of Mines experimental furnace. The necessity of frequent and extensive stack repairs as existing on these European furnaces does not offer any inducement to us to follow their example.

I heartily indorse the suggestion contained in the last item of the authors' summary and wish to suggest merely that the maximum of contact between gas and solids, the attainment of which is equivalent to highest reducing efficiency, might be more safely approached by a gradual change from an open center and a dense periphery than in furnaces working under the reverse conditions.

Mr. A. J. Boynton:* Ever since these investigations started I have been much impressed with their value, and, so far as my experience enables me to determine, the conclusions reached are all capable of reasonable interpretation. I believe it is difficult to realize at present the value of these researches, which, if continued and extended, will be the basis of much that is done in connection with the blast-furnace of the future. I feel that the thanks of every man here and those of every man in the furnace industry are due to these gentlemen for the skill and painstaking care with which they have made these surveys and the good judgment exercised in the selection of matters of primary importance for investigation.

Mr. A. C. Fieldner:† I am not a metallurgist, my interest being primarily in the fuel side of the problem; but in behalf of the Bureau of Mines I wish to say we are deeply indebted to the blast-furnace industry for their co-operation in this work, and for their free and frank criticisms and their helpful suggestions, which have made the investigation possible. We in the Bureau of Mines are

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†Superintendent, Pittsburgh Experiment Station, and Chief Chemist, U. S. Bureau of Mines.

interested in the combustibility of coke from other points of view as well as that of the blast-furnace operator. For instance, the American Gas Association has, during the past summer, made tests on six different gas-manufacturing installations of different types of retorts or ovens, using Pittsburgh coal from the same mine. One of the objects of these tests was to determine the effect of retort or oven design and manner of carbonization upon the properties of the coke produced.

Combustibility, ease of ignition, and ease of holding a fire under reduced draft are significant properties which seem important in connection with the use of coke in house-heating furnaces. The term combustibility has been very loosely used. The definitions of combustibility* vary from "that variable property of cokes by virtue of which it is possible to maintain a higher tonnage and produce a ton of iron with a smaller amount of one coke than of another," to "the speed at which the carbon molecules in the coke combine with oxygen under given conditions."

Perrott and Kinney† realized the need of a clear definition for the term combustibility, and state in terms of blast-furnace operation "the combustibility of fuel burned at the tuyeres is inversely proportional to the distance from the tuyeres at which oxygen and carbon dioxide have disappeared, or in other words, directly proportional to the space rate of disappearance of oxygen and carbon dioxide."

According to this definition, "the extent to which combustion has proceeded at any point in the fuel bed may be conveniently expressed as the ratio between the percentage of carbon in the gases at that point and the maximum percentage the gases can hold, i. e., when they consist of CO and N_2 only." Percentage combustibility is therefore expressed by the ratio, $\frac{CO_2 + CO}{2\ (CO_2 + O_2) + CO} \times 100.$

Sherman and Blizard‡ have used this same expression for determining the combustibility of cokes in fuel beds, their tests being made in a cylindrical furnace with a grate area of one square foot. This method of defining combustibility has recently been accepted by the

*New light on the combustibility of coke, by A. C. Fieldner, Chemical and Metallurgical Engineering, 1923. v. 29, p. 1052.

†Combustion of coke in blast-furnace hearth, by G. St. J. Perrott and S. P. Kinney. Trans. A. I. M. and M. E., 1923. v. 69, p. 543-583.

‡Combustion of blast-furnace cokes in fuel beds, by R. A. Sherman and John Blizard. Trans. A. I. M. and M. E., 1923. v. 69, p. 526-542.

English investigators, Foxwell and Wheeler,* who state that "the combustibility of a coke may be defined as that property which determines its rate of reaction with pure oxygen or with air at a given temperature." They definitely restrict the term combustibility to the rate of interaction of coke with air or oxygen and recommend the use of the broader term reactivity to denote "ability of coke to react with either oxygen or CO_2."

It is possible that high reactivity of coke with air also means high reactivity with CO_2. Not enough experiments have been made to determine whether this is true. If reactivity is a function of the microscopic surface condition of carbon, then we would expect that that particular coke which has the highest reactivity with CO_2 would also have the highest reactivity with air. This particular phase of the problem is now concerning scientific investigators in Germany, England and the United States. In the Bureau we are agreed with the British investigators (1) that methods of testing in which the rate of interaction of the coke with either air or oxygen is determined should be regarded as measuring its combustibility; (2) that methods in which the rate of reduction of CO_2 is measured should be termed tests of the reactivity of the coke, and that for the present the question is open of whether for a number of different cokes the relative combustibilities are the same as the relative reactivities.

Evans† in a recent paper gives values for the relative reactivities of different cokes, starting with the hardest bee-hive coke as the least reactive and ending with charcoal as the most reactive. In between these two extremes are found, in order of increasing reactivity, by-product coke, gas-house coke, low-temperature coke, and lignite char. Much of our lack of progress in correlating the physical properties of coke with its use in the blast-furnace and other furnaces has been due to a lack of clear definition of these properties. Rapid progress is now being made in limiting these definitions to particular tests so that correlation will be possible ultimately.

Mr. L. A. Touzalin:‡ I understand that this curve showing the analysis of the furnace hearth gas is taken at the nose of the

*The testing of coke, by G. E. Foxwell and R. V. Wheeler. II, Fuel in Science and Practice, 1925. v. 4, p. 410-413.

†Solid smokeless fuels; their properties and uses, by E. C. Evans. Journal of the Society of Chemical Industry, 1925. v. 44, p. 383-391.

‡Superintendent of Blast-Furnaces, Illinois Steel Co., Joliet, Ill.

tuyeres, and was the average from about 13 furnaces. What was the range of blast temperature on these furnaces when such analyses were made, and did the curve show any relation to the blast temperature?

MR. T. L. JOSEPH: The blast temperature covered quite a range; I think from 900 to perhaps 1200 degrees F. It was impossible to connect the gas composition in the tuyere zone with operating conditions. The surprising thing was that the change in the size of the combustion zone was very small from furnace to furnace. Textbooks refer to oxygen penetrating the middle of the furnace, and also state that it reaches the top of the bosh. It has been shown by Perrott and Kinney, however, that combustion is confined to a space extending 30 to 40 inches from the nose of the tuyere; that this condition exists was not generally known. This is, to date, the outstanding contribution of the investigation.

With regard to the distribution of the gas stream in the top part of the furnace, I quite agree with Mr. Mathesius that it depends on the resistance of the charge, the gas following the line of least resistance. If the stock is distributed uniformly in the top of the furnace, there will be an equal distribution of the gas stream. However, as pointed out in the paper, more rapid descent of the charge in the outer portion of the furnace would also affect the CO_2 content, because of a fresh supply of ore in this part of the furnace. To what extent the unequal descent of the charge influences the composition of the gas stream is an open question.

MR. W. MATHESIUS: I would like to call attention to the fact that if the travel of the stock in all furnaces (after the material has been deposited in them as we do) were uniform throughout, the same quantity by weight being consumed per square foot of area in the lower part of the furnace, we could not help but get the material running faster in the center, as the porosity of the stock in the center is greater than on the sides. We do know that the movement of the stock at the tuyeres, or immediately above the tuyeres, is not uniform across the area of the furnace, and I think we deliberately aim to offset that by charging our materials so as to effect compensation in the opposite direction.

We should concede that utilization for reduction purposes per cubic foot of stack content is very likely less in our practice than would obtain in a theoretical furnace with uniform porosity throughout. Variations in size of our materials do not permit such uniformity. After all, the cost of building a stack does not go up in proportion to the cubic content; and, in building a furnace larger, I believe we should be satisfied with somewhat less reducing efficiency per cubic foot of furnace volume, as long as we obtain greater production at a lower cost.

MR. J. C. BARRETT:* About thirty feet from the top we go in to see how things lie in blowing in a furnace, and, if you go down that far, it is more or less level, and, if the bell unloads irregularly, the stock will build up on one side. It will also show a tendency within a couple of feet from the side wall to give a little bit of a rise and then a depression in the middle. This is the condition we find after filling the furnace while cold.

Before we are through blowing in, of course, we fill the furnace to within three or four feet of the bell, and then our cup and cone is quite distinct, with probably about a five-foot depression in the middle. This is the condition your furnace is in when through. We at times take out a bell after being in service for a time, and it then shows that your furnace within a few feet of the bell still has that form.

We have at times blown the furnace down 40 feet for inspection, but when you are down that far you don't find the above condition. Your condition is then more nearly level; or, if anything, high in the middle. That is possibly due to the fact that while we are blowing down we try to protect the top of the furnace and see that the heat is not too high. In doing that we add a little cold stock, which naturally would deflect to the middle of the furnace.

That is as far as I can comment on the condition as portrayed. I like the talk very much. It gives an idea of some of the reductions and reactions that take place in the furnace. Regarding the line of CO_2, it looks pretty reasonable to me that where you take the gas from the side of the furnace you will find more oxygen on account of the manner in which the fine ores take to the side. The gas at that

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point would have less CO_2 than in the middle of the furnace. It looks theoretically correct to me. As I interpret the lines, it is not so much a flow of the stock downward as the flow and reaction of the CO_2 in the furnace.

MR. T. L. JOSEPH: We did not include in the paper anything about stone. We found in the little furnace that there seems to be no metallurgical reason for charging pieces of limestone four inches in diameter.

I should like to raise the question whether or not it is advisable to use limestone of smaller size. We found that large pieces get well down into the furnace before being completely calcined. The CO_2 given off at these lower positions reacts with C to form CO, causing "solution loss."

A METHOD OF DETERMINING COMPARABLE BLOWING PRACTICES FOR IRON BLAST-FURNACES*

By J. S. Fulton†

Many improvements have been made in blast-furnace practice in past years. The furnace lines have been changed; better mechanical equipment has been installed around the furnace; and more attention has been paid to the metallurgical values of the raw solids entering the furnace. As a result of these improvements the tonnage of iron made by each furnace has increased in spite of poorer and leaner ores. Now still greater tonnages are demanded, and, in addition, all the production costs are closely scrutinized.

While all these improvements were being made, it is unfortunate that the greatest amount of raw material entering the furnace should remain invisible. This very invisibility is probably the direct cause of so little attention having been paid to the exact amount of the air (wind or blast) entering the furnace. The weight of this wind is astonishingly large, as an example will show. A 600-ton furnace requiring 40,000 cubic feet of free air per minute at 32 degrees F. and 14.7 pounds absolute, has delivered to it nearly 2100 long tons of air each day of 24 hours. This weight practically equals the weight of all the solid raw materials entering the furnace in the same period of time. The power required for compressing and delivering this amount of free air is large, and will become larger as the demands for greater tonnage are met. Considerable reductions can be made in the various items entering into the cost of wind for a furnace.

Most blast-furnaces are now blown by reciprocating blowing tubs driven by either steam-power or gas-power cylinders. Little knowledge exists of the actual volume of free air entering the furnace. This lack of knowledge is primarily due to the impossibility of accurately metering a pulsating flow. Since the furnace men could not meter their blowing tubs and yet had to blow their furnaces, some used correction factors to be applied to the piston displacement of the tubs in order to approximate the actual free air delivery. While some of the furnace men used a correcting factor, the majority did

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†Special Representative, Ingersoll-Rand Co., Pittsburgh.

not, and yet the average furnace performance as far as blowing practice was concerned was about the same. Such correcting factors as have reached our attention were entirely too optimistic. A great deal less of the piston displacement than was figured appeared as actual free air in the furnace.

The furnaces run on the amount of free air they actually receive, which bears no relationship to the amount of wind reported.

While the blast-furnace is a machine, and so not endowed with actual life, yet in its operation it approximates some of the functions of a living organism. It ingests, digests, and breathes. It can not live without being supplied with an amount of oxygen in proportion to its labor. A deep-sea diver, in his suit and helmet, lives and works under water because his "tender" forces the free air down to him by means of an air pump. The diver lives on the amount of free air delivered to him. The same is true of a blast-furnace.

American furnaces are blown on the theory of constant wind. This is a perfectly sound theory, as a pound of dry carbon will require almost exactly the same number of pounds of oxygen to give a chemical balance in the top gases for all coke rates; but a little investigation shows that, in practice, constant wind means constant revolutions per minute of the blowing tub. While, as stated before, it was recognized that the actual delivery of free air per revolution would vary for different operating locations, temperatures, etc., it was assumed that these variations would be slight. In consequence, a practice was built up around the cubic feet of wind per pound of coke. From 50 to 55 cubic feet of wind per pound of coke was considered good practice, and a departure in either direction from these values indicated dubious practice. If all plants were uniform and at the same barometer pressure and air temperature; if they were provided with the same ore and coke and accounted for their raw materials in the same itemized manner; if their time on blast and their production were recorded in the same way; then the cubic feet of wind per pound of coke would serve as a basis of comparable blowing practice. Unfortunately, such is not the case, and we find wide variations in value among different furnaces for supposedly the same terms.

Time off Blast. The methods are widely divergent in reporting the minutes actually on blast. It will be admitted that if we take

away from the 1440 minutes per day the minutes the blast is off the furnace for checks, casts and repairs, we should have the minutes the furnace was blown; yet we find monthly reports indicating that a furnace was off blast less than seven minutes a day. Other furnaces, also without major repairs, report over 40 minutes off blast.

Revolutions per Minute. Few engines have revolution counters, and fewer still recording tachometers. A great many have blackboards in the engine-room upon which the revolutions ordered are posted. These posted figures are frequently reported as the day's run regardless of the actual number of revolutions operated.

Actual Delivery of Free Air. To determine the discrepancy between piston displacement and actual free air delivery it is only necessary to consider the factors affecting delivery in any blowing-engine running to give constant wind. These are:

1. The actual delivery of free air per revolution decreases in each blowing tub with an increase in blast pressure, because the increased blast pressure: (a) increases the re-expansion losses on the suction stroke from the air compressed into the clearance space at the end of the cylinder by the previous compression stroke; (b) increases the amount the entering air is preheated by the heat left in the cylinder from the previous compression stroke; (c) increases the leakage past valves and piston, and thus (d) cuts down the actual delivery of free air.

2. The actual delivery of free air per revolution decreases with an increase in r.p.m., because the increased velocity through the valves and ports causes increased friction on the air. This increased friction on the entering air reduces its absolute pressure and so reduces the weight of air drawn into the cylinder.

3. The actual delivery of free air per revolution decreases with the deterioration of the air-valves and piston-rings.

4. The actual number of r.p.m. depends upon the sensitiveness of the governor to variations in blast or steam conditions. To give a constant rate of r.p.m. (constant wind) the governor must be as sensitive at half speed and maximum blast pressure as it is at full speed and normal blast pressure.

Now all these factors have a changing value for each blowing-engine, and another value for some other blowing-engine, and probably a different value for either blowing-engine at some other time and under other operating conditions.

Weight of Oxygen per Cubic Foot of Air. Since air is a gas, it expands in proportion to any increase in its absolute temperature or a decrease in its absolute pressure. An increase of 10 degrees F. in temperature, or 0.3 of a pound decrease in pressure of the air entering the blowing tub, increases the volume two per cent.; or, expressed another way, requires two per cent. more power for the compression and delivery of a required weight of free air. It is not unusual to find blowing tubs taking their air from the top of the blowing-engine house or even from the basement. At both these points the air is superheated and is carrying more moisture than the outside air. Roughly, a rise in temperature of 20 degrees F. doubles the moisture-carrying capacity of the air.

Pounds of Coke per Long Ton of Iron. This would seem to be a definite statement of the amount of coke entering the furnace and from it the pounds of carbon could be obtained. Unfortunately, this figure on the monthly reports varies to suit the definitions of the different accounting departments. As a bookkeeping figure it is probably correct and so balances at the end of the month the weight of coke received and coke consumed. As a figure to be used in a comparison of furnace practice, it is almost useless. It is not uncommon even in the same corporation to find different interpretations of the various plus and minus charges. At the same time, the physical character of the coke varies; the screens vary in size and in mechanical condition; and the coke is stored for a different length of time out in the open.

Some of the different methods of determining the "reported pounds of coke" follow:

1. Pounds of unscreened coke as received at the furnace, sometimes corrected (a) to a fixed percentage of moisture; (b) to a dry basis.

2. Pounds of coke as screened at the furnace, sometimes corrected (a) to a fixed percentage of moisture; (b) to a dry basis; (c) to a net basis of large coke entering the furnace with the braize

used elsewhere in the plant; (d) to a basis where all the coke is charged against the furnace, because the braize screened out is used under the boiler.

3. Pounds of coke as shipped, by car-loads or barge weights, adjusted at the end of the month to make the books balance, even though the coke was weighed into the furnace for a different total. This is generally on a wet basis without correction for the percentage of moisture.

4. Pounds of coke in its natural state determined from the volume of the charging buggy or even the skip.

Chemical Analysis of the Coke. Belonging both to this and the previous paragraph is the subject of over-quenched coke. When the coke is over-quenched the furnace man is sometimes required to pay the full price of coke for the excess water. Other plants allow a credit in weight for over a certain percentage of moisture. In either case the excess water requires additional carbon in the furnace to evaporate it. The percentage of fixed carbon in the dry coke depends upon the character and combination of the raw coals entering the coke-ovens. The reported fixed carbon in the dry screened coke varies from 92.46 to 82.6 per cent.

While each of these individual variations in plant practice, plant material and plant accounting is small, yet the sum of the variations applying to any comparison is not small; and, worse than that, has an indeterminate value, without a thorough investigation.

When we consider all these variables, it is hard to see how any specific number of cubic feet of air per pound of coke can be good and correct practice, and any other number of cubic feet be poor and incorrect practice. Yet the furnace men had to have some means of comparable performance and were forced to use the values derived from reported practices. There is no intention of criticizing the operators for using these values; in fact, they are to be commended for producing the furnace results they have with the means at hand.

As was stated previously, the furnaces run on the amount of free air they actually receive, which bears no relationship to the amount of wind reported. Now, from this statement, is it possible to determine a measure of the wind performance of any furnace?

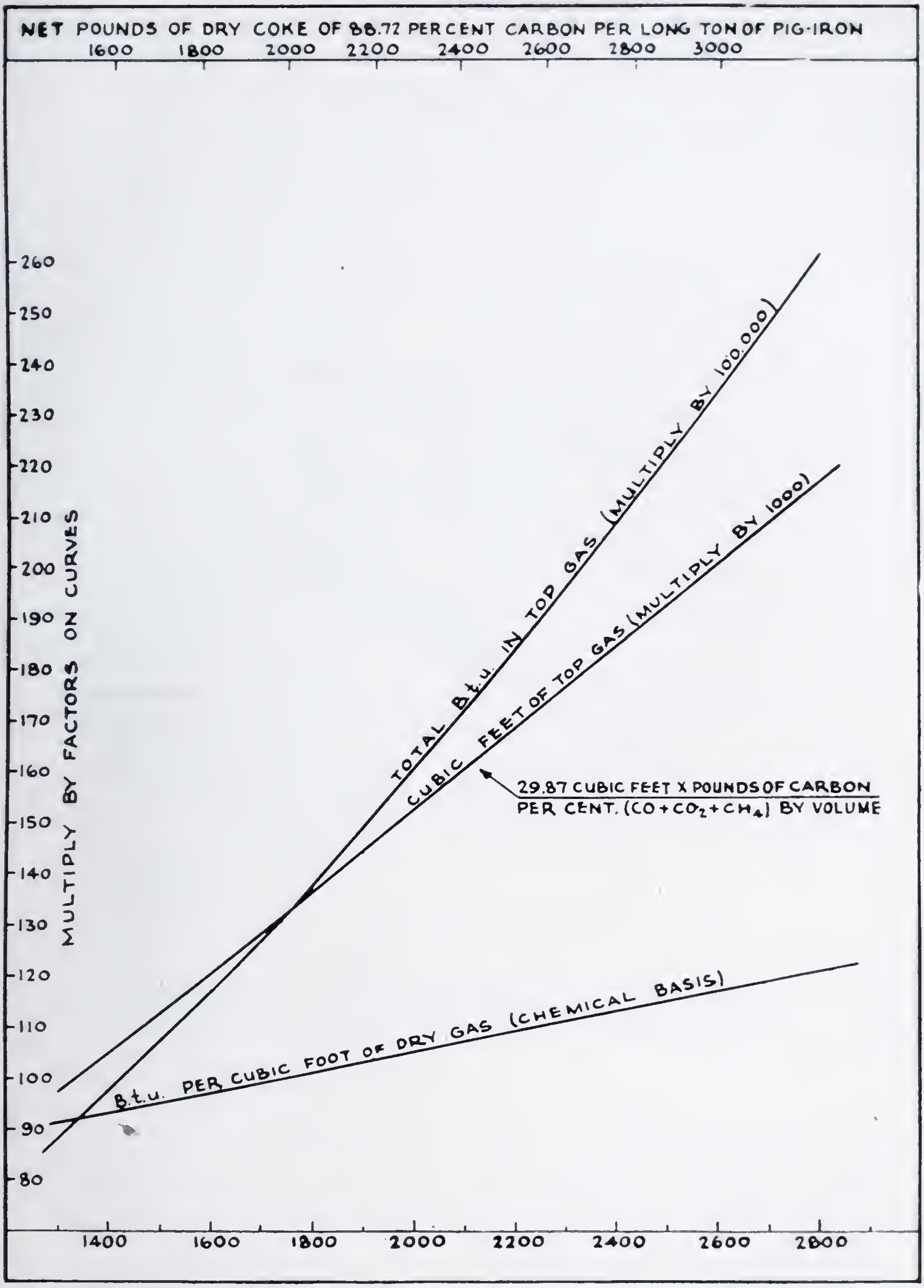

Fig. 1. Gas Analysis for Various Carbon Rates.

If we carefully analyze the monthly report of a furnace we can determine the actual free air in the blast from the nitrogen in the top gas. This can also be determined by a carbon-oxygen check of

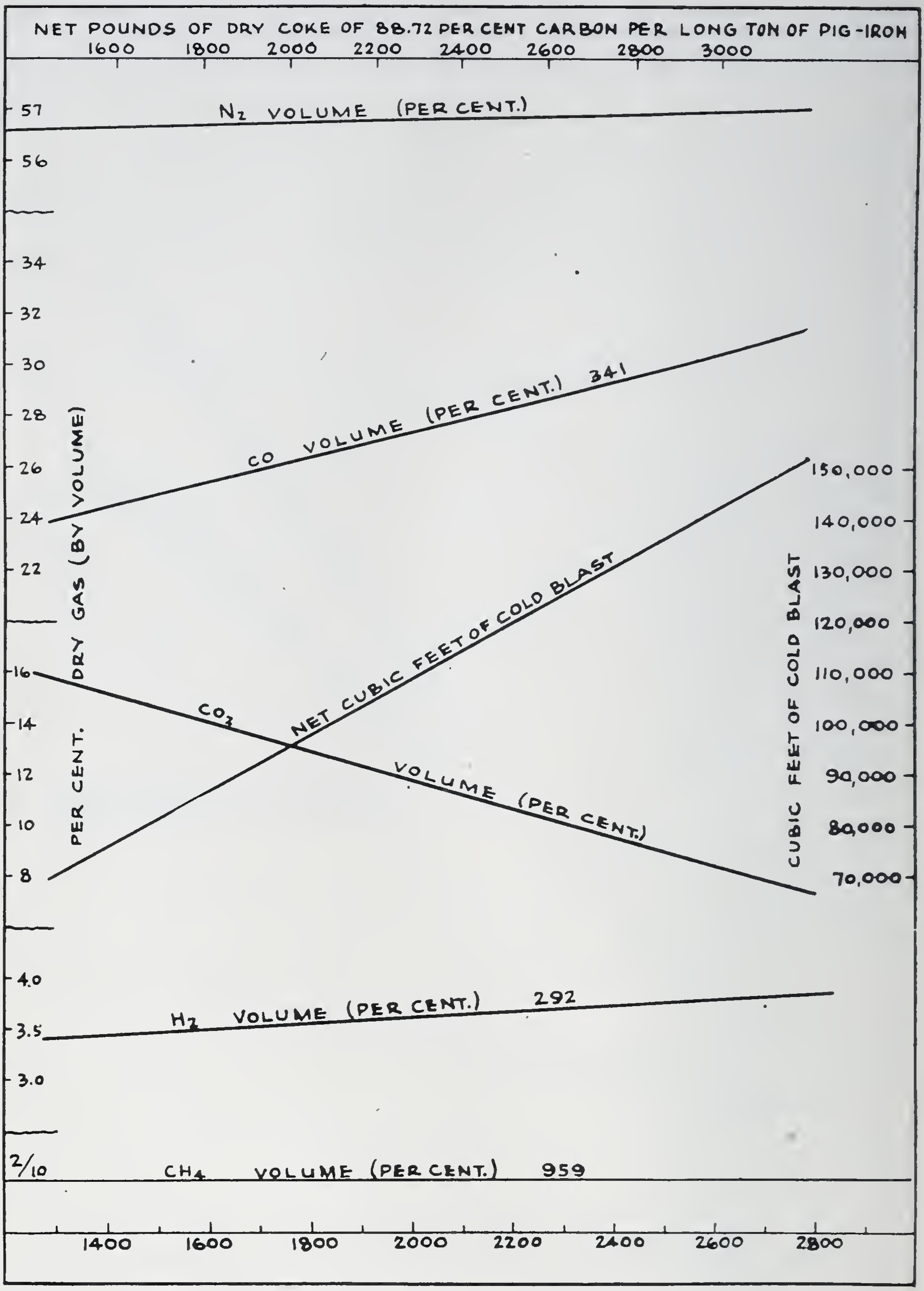

Fig. 2. Cold Blast for Various Carbon Rates.

coke, ore and stone entering the furnace, and the flue-dust, slag, iron and top gas leaving the furnace. Either method will be as accurate as the chemical analysis of the top gas, since the oxygen in the blast

combines with the carbon in the coke to produce the carbonized top gases. The cubic feet of free air in the blast per long ton of iron will be almost in proportion to the pounds of carbon per long ton of iron.

Fig. 1 shows this volume, together with the average analysis of the top gas for different carbon rates. The volumes are all at 32 degrees F. and 14.7 pounds pressure, absolute and dry. We have derived these curves from the well known Bacon-Brassert curves presented before the American Iron and Steel Institute,* on coke rates with coke of 88.72 per cent. fixed carbon, and from H. P. Howland's paper before the American Institute of Mining Engineers.† Thanks are due them for their presentations, which have made this latter investigation possible. The average values of gas analysis have been checked with results from a number of furnaces. In Fig. 2, the curve of "net cubic feet of cold blast" has been derived from the formula; net cubic feet of cold blast at 32 degrees F. and 14.7 pounds absolute and dry per long ton of pig-iron $= \frac{C \times D \times G}{V \times N}$, in which $C = 29.87 =$ cubic feet of dry air required per pound of carbon in the top gas; $D =$ pounds of dry carbon, entering the furnace in the coke, per long ton of iron; $G =$ percentage, by volume, of nitrogen in the top gas; $V =$ percentage, by volume, of $(CO + CO_2 + CH_4)$ in the top gas; and $N =$ percentage, by volume, of nitrogen in the air.

From the curve we can pick the net cubic feet of cold blast at 32 degrees F. and 14.7 pounds absolute and dry for any number of pounds of dry carbon, per long ton of pig-iron. The cubic feet of wind reported can be reduced to the same basis. Then

$$\frac{\text{net cubic feet}}{\text{reported cubic feet}} = \text{plant volumetric efficiency.}$$

This value shows the percentage of reported wind accounted for in combination with the carbon in the top gas. Of course, included in this value is an amount that covers the compressed air dissipated by leaks between the blower and the furnace, by stove changes, by checks, and by casts; this amount is close to five per cent. "Plant volumetric efficiency" is used for want of a better phrase. In a way, this relationship is an efficiency, as it is a ratio between gross and net. Whatever it may be called, it will serve as a basis of comparable

*Year Book of the American Iron and Steel Institute, 1914, p. 15-69.
†Trans. A. I. M. E., 1917, v. 56, p. 339-364.

blowing practice between two furnaces, regardless of the type of their blowing equipment.

To make a fair comparison of different furnace performances, the following data are essential:

1. Long tons of iron produced per day, as averaged for at least a month.

2. Net pounds of dry carbon in the coke actually entering the furnace per long ton of iron.

3. Cubic feet of wind reported per minute blown, at its intake temperature, humidity, barometric pressure, and blast pressure.

4. Minutes actually on blast per day, after allowing for checks, casts, and repairs.

From the above, there may be developed:

5. The cubic feet of air at 32 degrees F., 14.7 pounds absolute and dry required for the carbon rate in item 2.

6. When brought to the same temperature, barometric pressure, and humidity, item 5 divided by item 3 will show the percentage of the wind accounted for, or the plant volumetric efficiency.

7. Adiabatic air-horse-power hours for compressing and delivering the wind specified in item 3 may be developed.

8. The adiabatic horse-power hours may be apportioned per long ton of iron or short ton of carbon.

Table I (folding plate) shows the results from a number of plants.

The cubic feet of air per pound of coke, as reported, varies from 47.5 for No. 23, to 70.8 for No. 11, or a variation of 49 per cent. Obviously, the furnaces could not have worked satisfactorily for a month if their actual receipts of air were off by this amount.

Again, furnaces 1 and 2 are blown by the same make and type of engines in about the same mechanical condition, and there we find:

	No. 1	No. 2
Method of blowing	Blowing tubs	Blowing tubs
Plant volumetric efficiency	81.3	79.5
Cubic feet per pound of coke, as reported	57.2	61.5

Though in different locations, and under different accounting rules, they are closer on their plant volumetric efficiency (2.5 per cent. in favor of No. 2) than on their cubic feet per pound of coke (7.5 per cent. in favor of No. 1).

Comparing No. 10 and No. 20, we find:

	No. 10	No. 20
Method of blowing	Blowing tubs	Turbo-blowers
Plant volumetric efficiency	81.4	94.8
Cubic feet per pound of coke, as reported	54.5	55.4

Here the coke volumes are within 1.6 per cent. of each other, while there is a difference of 16.4 per cent. in the amount of air accounted for. The plants are in different locations and under different managements.

It is possible to compare even widely divergent furnace practices on the basis of plant volumetric efficiency:

	No. 3	No. 8	No. 14
Long tons of pig-iron	631	151	513
Pounds of coke	1950	4688	2159
Method of blowing	Blowing tubs	Blowing tubs	Blowing tubs
Plant volumetric efficiency	82.5	83.0	82.8
Cubic feet per pound of coke, as reported	66.1	59.8	57.6

Here the plant volumetric efficiencies have a maximum departure of 0.61 per cent., while the cubic feet per pound of coke reported varies by 14.7 per cent.

So long as you do not recognize the exact amount of free air entering your furnace, just that long will you also fail to know the cost of blowing your furnace. Of course, we must be careful when we approach the subject of blowing costs; for linked in with them are, or should be, some very nice credits from B.t.u.'s in the gas or steam furnished to other departments. Maybe you get credit for this and maybe not. A plant has recently come to our attention where the monthly credit to the furnaces, for the steam delivered to drive a very considerable steel plant, is less than the charge for the coal used in the pilot fires under the gas-fired boilers. Anyhow, you can start with the same basis of comparison, but that is far enough to go along that line now.

Again we must emphasize that "the furnaces run on the amount of free air they actually receive, which bears no relationship to the amount of wind reported."

In closing, we wish again to express our thanks to the authors whose subject matter has been drawn upon; to the furnace men for their patience and co-operation; and to the engineers for their help in working this into shape.

TABLE I. DAILY PERFORMANCE OF BLAST-FURNACES FROM MONTHLY REPORTS

	DESCRIPTION	FURNACES — Blowing-Engines											
		1	2	3	4	5	6	7	8	9	10	11	12
1	Long tons of iron per day	658	773	631	536	559	601	442	151	[illegible]	301	572	300
2	Pounds of coke per long ton of iron	1070	1450	1950	2135	2147	1090	2171	4658	2190	2015	1699	2545
3	Net pounds of carbon per long ton of iron	1070	1200	1830	1760	1810	1705	1775	1000	1770	2110	1470	2100
4	Degrees F. of air entering blower	40	40	62	50	60	60	65	55	65	34	74	45
5	Absolute air pressure entering blower	14.5	14.6	14.5	14.5	14.45	14.45	14.4	14.5	14.4	14.5	14.6	14.5
6	Blast pressure pounds per square inch gage pressure	18.0	20.0	13.5	16.1	19.05	16.15	15.0	12.75	16		.	11.5
7	Type and size of blowing equipment	2 84x48	1 84x45	84x60	5 86x60	96x60	96x60	84x60	84x60	R	R	R	84x60
8	Piston displacement per revolution	613	613	750	400			760	377	[illegible]		. .	377
9	Revolutions per minute, reported	50	50	65	?	50.2	54.4	56.5	70			. . .	59
10	Cubic feet reported, per day	52,700	40,000	51,700	10,200	50,209	54,451	43,000	20,500	51,500	30,400	48,970	33,600
11	Minutes blown per day	1405	1110	1410	1410	1121	1400	1420	1417	1420	1410	1405	1417
12	Assumed volumetric efficiency	94.5	94.5	93.0	91.6			95.5		91	. . .		.
13	Assumed actual air delivery	49,600	46,200	17,057	14,900	50,200	54,151	42,342		18,500	.		.
14	Cubic feet of air chemical basis per long ton iron at 32° F. and 14.7 lb. absolute	90,000	69,000	85,500	95,500	105,000	92,000	90,000	219,000	[illegible]	114,000	80,000	119,000
15	Cubic feet of air chemical basis per minute at plant temperature and abs. pres.	42,800	19,000	42,600	40,400	41,300	17,300	42,100	24,700	49,000	21,700	35,800	26,600
16	Plant volumetric efficiency, (item 15) ÷ (item 10)	81.3	70.5	82.5	82.1	82.1	77.8	90.0	83.0	81.0	81.1	73.0	79.1
17	Cubic feet reported per pound of coke, (item 10) ÷ (item 2)	57.2	61.5	66.1	61.5	59.3	61.8	63.6	59.8	18.5	E 54.5	E 70.8	61.0

	DESCRIPTION	FURNACES — Blowing-Engines				Turbo-Blowers						
		13	14	15	16	17	18	19	20	21	22	23
1	Long tons of iron per day	525	613	432	463	655	510	610	627	290	610	763
2	Pounds of coke per long ton of iron	2161	2150	2066	2051	1627	1715	1910	1700	2000	2112	1956
3	Net pounds of carbon per long ton of iron	1820	1815	1750	1710	1075	1450	1570	1410	1040	1760	1873
4	Degrees F. of air entering blower	55	55	80	80	52	70	60	75	75	60	32
5	Absolute air pressure entering blower	14.6	14.0	14.6	14.7	14.6	14.2	14.2	14.2	14.2	14.3	14.7
6	Blast pressure pounds per square inch gage pressure	17	17	18	18.1	16.0	15.0	15.0	17.0	12.0	13.1	20
7	Type and size of blowing equipment	R	R	[illegible]	All [illegible]	T	T	T	T	T	T	T
8	Piston displacement per revolution					.	.					
9	Revolutions per minute, reported	98										
10	Cubic feet reported, per day	17,700	15,750	11,100	41,800	41,700	45,000	14,000	12,000	11,000	11,000	50,000
11	Minutes blown per day	1408	1391	1383	1390	1410	1110	1110	1110	1415	1410	1120
12	Assumed volumetric efficiency	.										
13	Assumed actual air delivery			11,100		11,700	45,000	41,000	42,000	21,000	41,000	50,000
14	Cubic feet of air chemical basis per long ton iron at 32° F. and 14.7 lb. absolute	98,000	97,500	90,000	91,000	99,500	78,000	85,000	78,000	80,000	95,500	91,000
15	Cubic feet of air chemical basis per minute at plant temperature and abs. pres.	38,100	37,900	11,000	31,000	14,000	11,600	12,100	10,900	20,500	17,800	48,400
16	Plant volumetric efficiency, (item 15) ÷ (item 10)	80.7	82.5	80.9	80.3	99.0	101.1	95.0	91.8	97.5	92.3	96.5
17	Cubic feet reported per pound of coke, (item 10) ÷ (item 2)	59.0	57.6	63.6	61.2	49.6	T 55.5	51.6	55.4	51.2	52.9	17.5

DISCUSSION

Mr. W. P. Chandler, Jr.:* I have listened to Mr. Fulton's paper with pleasure and I feel that a great deal of value has been accomplished. However, one very important thing in the blowing of a furnace is that, while we may not know exactly the amount of air we are putting into it, we are probably putting in all that it will take. Maximum tonnage is obtained by burning a maximum amount of coke, and the limiting factor is the amount of blast which can be introduced into the furnace. A measurement of the exact quantity of wind being blown may indicate too little air, but if a maximum amount is being introduced the pressures will undoubtedly be high and an increase in air blown would be impossible. At the same time, there is no real excuse for not knowing exactly what is going on, as that must be the starting point for any improvement.

Another interesting point in the paper was Mr. Fulton's plant efficiency, as he calls it. This value lies in the neighborhood of 80 per cent. on his reciprocating engines, and 95 per cent. on his turbo-blowers. The turbo-blower air is measured at the intake, and there is no chance for leakage other than through the stoves, walls, etc., and possibly that is what he referred to in his five per cent. loss beyond the engines. Adding that five per cent. to the 80 per cent. he has from his reciprocating engines would bring the volumetric efficiency to around 85 per cent. for the engines themselves.

When attempts are made to measure volumetric efficiency on reciprocating blowing-engines, values are obtained anywhere from 85 to over 100 per cent. However, the volumetric efficiency as calculated and the volumetric efficiency as determined from an indicator card—if the temperature rise in the cylinder is considered, and the valves are tight—should check very closely. From a number of determinations with indicators 87 per cent. appears to be a fair value. As I am not familiar with the studies Mr. Fulton has reported, the discrepancy between 87 and 85 per cent. might easily be accounted for. Regarding the general method of calculation Mr. Fulton brings out, I think a chemical balance on the furnace is the only way you can tell exactly what air you are getting into the furnace with reciprocating blowing equipment.

*Special Engineer, Carnegie Steel Co., Pittsburgh.

Mr. W. Mathesius:* Mr. Fulton has painted for us a rather dismal picture of the inadequate consideration given by us blast-furnace men to the air requirement of our furnaces, and of the lack of efficiency and uniformity prevailing in reference to questions of blast supply.

While I do not wish to deny that there may be furnaces which are afflicted with all, or nearly all, of the ailments and deficiencies cited in their equipment, operation, maintenance, and accounting, yet I feel justified in asserting that a number of furnace plants have clearly recognized the desirability of supplying the blast with the same degree of uniformity which is more commonly conceded as essential in charging the solid burden constituents. The improvement of their practice over the results of former years, sometimes accomplished in the face of a less favorable situation as to raw materials, is in my opinion eloquent proof that these plants have converted their thoughts into deeds and found the reward well worth their efforts.

I believe it might be advisable to separate the subject, which Mr. Fulton has so interestingly presented, into two parts. The first of these would be concerned with a comparison of the blowing practice of individual stacks of the same plant, while the second chapter would deal with the comparative performance of separate works.

For the reasons given by Mr. Fulton—namely, the same barometer and temperature conditions, uniform accounting standards and itemization of raw materials, and uniform methods of reporting blowing-engine practice and production—the term "cubic feet of wind per pound of coke" is, in my opinion, a convenient and reliable index of comparative blast delivery practice between individual furnaces of the same plant. That the values computed in this way may at times be rather far from expressing the actual volume of air entering the furnace I should gladly concede; but as a comparative factor, to be currently determined and used in practice, it would seem to be preferable and to promise a greater degree of accuracy than the result calculated from Mr. Fulton's formula for wind actually delivered, because the only feasible means of reliably securing, in practice, the data on "dry coke-carbon used per ton of iron" and on "top gas analysis" is, in my opinion, the method of averaging these figures for a considerable

*Assistant General Superintendent, Illinois Steel Co., South Chicago, Ill.

number of operating months. For this reason I do not believe Mr. Fulton's suggested formula to be applicable to the current supervision of blowing practice which is necessary for the attainment of uniform and constant air delivery.

If, on the other hand, it is desired to compare the blowing practice of separate works with different operating and accounting standards and under diverse conditions regarding raw materials, Mr. Fulton's suggested method of comparison should be found most helpful. Particularly where determinations are to be made of the blast volume actually required—for instance, for the purpose of arriving at the capacity of contemplated blowing-engine installations—this calculation would seem to fill a long-felt want.

While this same method of calculating the blast quantities actually delivered would also permit of making reliable comparisons between plants as to the cost of the blast supply, I think it feasible to arrive at reasonably accurate data in this respect by merely figuring the monthly cost of blowing per ton of dry coke-carbon charged. In any event this figure, which can be readily obtained in any plant, would not be seriously affected by omitting the gas-analysis factor where standard grades of iron are produced within the usual range of coke consumption. I believe that on this basis useful cost comparisons may be currently made. They would be free from the inherent deficiency of the now more commonly accepted method of calculating blowing costs for a given volume of reported blast delivery, whereby equipment of poor volumetric efficiency is credited with a fictitiously low comparative cost.

MR. F. G. CUTLER:* The suggested method of comparison of blowing practices is of value in showing that present methods are generally inaccurate and sometimes misleading, particularly when decisions between types of blowing equipment are to be made. If it were possible to obtain accurate data for this method of comparison it would, no doubt, shed light on the volumetric efficiency of reciprocating blowing tubs. At our plant, where both reciprocating blowing

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tubs and turbo-blowers are used for blowing the same group of blast-furnaces, the operating records, when using the generally accepted factors for volumetric efficiency for blowing tubs, indicate that it requires considerably more blast to blow a furnace with reciprocating engines than with turbo-blowers.

Since the same furnaces, stoves, and blast lines are used it is apparent that the actual air delivery of the blowing tubs is not the displacement with an allowance for expansion of air in the clearance, and an allowance of considerable magnitude has to be made for leakage by valves and pistons, and heating of air in the tubs.

Mr. J. S. Fulton: We believe it will be agreed that, if the furnace is to work smoothly, the carbon and the oxygen entering it must be in the same proportion. If the carbon (coke) is charged at a constant rate the oxygen must be delivered at a constant proportional rate. Pounds of oxygen are required for combination with pounds of carbon. Now the weight of the carbon can easily be obtained, but it is very difficult to approximate the weight of oxygen delivered by a reciprocating blowing tub. It is possible to install large surge tanks on the intake to the blowing tubs and meter the actual flow of air into them. This inflow may then be transformed into weight of oxygen, but the proportion existing between the piston displacement and the actual delivery of the tubs is, unfortunately, true only for the particular day or hour, with all its local variables of barometer, temperature, blast pressure, r.p.m., etc. Even with identical blowing tubs operating on identical furnace conditions in the same plant, as Mr. Mathesius suggests, we are sure you will find in the different units a variation in the cubic feet of wind per pound of coke. It is true that these variations will be slighter than if the same tubs were in another plant with different local conditions, but, nevertheless, they can and do exist.

Mr. Mathesius has, unfortunately, charged this paper with blaming the furnace men for an inadequate consideration of their air requirements. Such was furthest from our thoughts, for we have always found the furnace men interested in their wind problem; yet they have had, in general, inadequate knowledge of the exact weight

of oxygen entering the furnace from their blowing tubs, day in and day out. By trial and error, they have obtained a working value for the volumetric efficiency of their tubs, and run their furnaces thus successfully; but their cubic feet of wind per pound of coke will not serve as a comparison between different plants.

We believe valuable results would be obtained if the different blast-furnace committees or associations were to combine in developing this or some other method of comparable blowing practice which would be applicable to the different plants.

BOARD OF DIRECTION

The regular monthly meeting of the Board of Direction of the Engineer's Society of Western Pennsylvania was held in the Wm. Penn Hotel, Tuesday, Dec. 15th at 4:40 P. M., President W. B. Spellmire presiding, Messrs. Ladd, Fohl, Weldin, Clifford, Dornbush, Edgar and the Secretary being present.

The Minutes of the last regular meeting held Nov. 17th, were approved without reading.

Applications for membership from the following gentlemen, having been published to the Society, pursuant to the action of the Board, were elected to membership:

MEMBERS

Diehl, David H. — McInerney, William I.
Hanst, J. Faber — Malevich, Vladimir

ASSOCIATE MEMBERS

Keagy, A. D. — Malseed, Wm. H.
Robinson, Mayes Randolph

ASSOCIATE

Thompson, Francis R.

JUNIOR

Hammer, Lewis E.

Applications for membership were received from the following gentlemen, and their names ordered published to the Society. Assignment to the various grades is as follows:

MEMBERS

Baker, David — Fishburn, Cyrus C.
Bakes, David, Jr. — Heald, Kenneth Conrad
Fairley, Geo. E. A. — Lewis, Edward Thomas
McCullough, H. F. — McWade, Frank J.

ASSOCIATE MEMBERS

Haworth, Mack E. — Wedderspoon, Arthur Alexander

JUNIORS

Spencer, Howard F. — Welker, Richard M.

Applications for reinstatement were received from the following and after discussion, the Secretary was requested to advise them of their reinstatement to membership.

Everhard, E. P. — Hower, H. S.

The Secretary reported the death of Mr. Frederick W. Winter, who joined the Society December 1903 and died Dec. 6, 1925.

The report of the Secretary, showing the financial condition of the Society at the close of business Nov. 30th, having been audited by the Finance Committee, was approved.

Mr. Clifford, Chairman of the Entertainment Committee, reported that two of the three speakers had been secured for the Annual Dinner and the third one would probably be secured within the next week. The date of the Dinner has been finally set as January 25th.

He also reported a very successful Ladies' Night party on Dec. 11th and presented a report showing a total attendance of 118, making a total receipt of $177.00, total expenditures of $235.00, net cost to the Society of $58.00.

In the absence of Mr. Leland, Chairman of the House Committee, the Secretary reported an evening attendance in the Society Rooms of 356 for the month of November.

In the absence of Mr. Affelder, Chairman of the Membership Committee, the Secretary reported that one meeting had been held to go over applications received since the last meeting and make assignment as to grades of membership.

In accordance with Article 5, Section 5 of the By-Laws, the Secretary presented the names submitted by the Nominating Committee for officers for the ensuing year, stating that they had been published to the Society and that no additional nominations had been received. It was, therefore, moved and carried that the nominees be finally approved and letter ballots mailed in accordance with the By-Laws.

The Secretary presented the following petition signed in accordance with Article 1, Section 8 of the By-Laws, requesting the formation of an electrical section:

To Board of Direction,
Engineers' Society of Western Penna.

DEAR SIRS:

Attention has been called to the fact that our Society is represented by sections in all the major branches of engineering except electrical. During the past few years quite a number of the members of the American Society of Electrical Engineers have accepted our invitation to join the Society, and a number of the others interested in electrical engineering activities, have urged the formation of an Electrical Section of our Society.

It is also our understanding that our President has recently held several conferences with the executive committee and officers of the local section of the A. I. E. E. with the idea of a possible affiliation with our Society and in order to complete this affiliation, in accordance with Section 1 Article 8 of the By-Laws, the undersigned respectfully petition your body to approve the formation of an Electrical Section of the Engineers' Society of Western Pennsylvania.

Respectfully submitted,

Geo. S. Humphrey,	John A. Hunter,
W. B. Spellmire,	Saul Lavine,
J. M. Graves,	Barton R. Shover,
M. R. Scharff,	M. E. Skinner,
Paul Caldwell,	E. C. Stone,
Jos. Bryan,	G. M. Gadsby.

After a general discussion, during which the President stated that he believed the Pittsburgh Section of the A. I. E. E. was ready to form an affiliation with our Society provided this Section was put into operation. It was moved and carried that the formation of this section be approved and the Secretary instructed to publish the petition in the regular announcement stating that a ballot will be taken at our regular meeing in January.

The Secretary presented the following report of the Special Committee appointed by the President at the last meeting of the Board to go into the matter of suggested changes in our rules governing the award of medals:

Board of Direction,
Engineers' Society of Western Pennsylvania.

DEAR SIRS:

The undersigned committee begs to report on proposed amendment of the rules of the Board governing the award of medals for excellence in papers presented before the Society.

Our report is based on results of questionnaire sent to members of the Medal Award Committee of recent years. Of ten replies received, seven

were in favor of a change, opening the competition to non-members of the Society. Of the three opposed, two gave as a reason the fear that the change might encourage the reading of papers before the Society for advertising motives, or at least reward good papers which were presented for that motive.

After carefully considering these suggestions, your Committee came to the conclusion that in their opinion the Society could be sufficiently protected against improper exploitation by the present rules requiring that papers should be judged upon their originality and usefulness to the profession.

Another idea presented to us was that it would hardly seem fair to award medals to men, who are eligible for membership, but not sufficiently interested in the Society to join. It appears to us, however, that there will be few cases where a man would be interested in the Society sufficient to present a medal paper and yet not care to join, if the advantages of membership were properly presented to him. If the Board agree to do so, an amendment could be made to our suggested rule by which the medals could be made available to members of all grades and non-members not eligible to resident membership.

Otherwise, we offer for action Rule 3, amended to read as follows:

"Medals shall be open for competition to all authors of papers. No person shall receive both medals in any one year. In case of award to a paper of joint authorship, separate medals shall be given to each author."

The last sentence, we believe, is in accord with the actual practice of the Society and suggest that it be recorded.

Respectfully submitted,

G. M. Goodspeed,
Wm. L. Affelder,
Wm. Archie Weldin, Chairman.

After a general discussion, it was moved and carried that the report of the Committee be approved and that Rule 3 be amended as suggested.

Mr. Weldin preesnted a report of the work of the Better Traffic Committee of Pittsburgh, of which he is a member as representative of this Society.

The president extended the thanks of the Board to Mr. Weldin for the work he is doing on behalf of the Society in serving on the committee.

The meeting adjourned at 5:40 P. M.

K. F. Treschow, *Secretary.*

JOINT MEETING—MECHANICAL SECTION, E. S. OF W. PA., AND PITTSBURGH SECTION, A. S. M. E.

The regular joint bi-monthly meeting of the Mechanical Section of the Engineers' Society of Western Pennsylvania and the Pittsburgh Section of the A. S. M. E. was held in Parlor 50, Wm. Penn Hotel, Tuesday, December 8th, at 8:18 P. M., Mr. Wm. Shaw presiding in the absence of the Chairman and Vice Chairman, 86 members and visitors being present.

The Minutes of the last meeting held Oct. 6th were read and approved.

No further business coming before the Section, the paper of the evening on The Evolution of Combustion Volumes in Pulverized Fuel Boiler Furnace Design was presented by Mr. H. W. Brooks, Consulting Engineer, Fuller-Lehigh Co., Fullerton, Lehigh County, Pa.

The ensuing discussion was participated in by: John A. Graham, Supt. Buildings & Grounds, Shadyside Academy; C. F. Weigel, Chf. Engr, The Walsh & Weidner Boiler Co, Chattanooga, Tenn; E. B. Plapp, Mech. Engr,

Heyl & Patterson, Inc; W. C. Buell, Jr., Engr, Rust Engineering Company; G. G. Bell, Mgr, Power Development, West Penn Power Co; E. K. Mosier, Dist. Stoker Engr, Service Dept, Westinghouse Elec. & Mfg. Co, Philadelphia, Pa; H. C. Medley, Draftsman, Heyl & Patterson, Inc; H. Coerper, Research Dept. Combustion Engineering Corp, New York, N. Y; Martin Frisch, Research Dept, Combustion Engineering Corp, New York, N. Y; Thomas A. Peebles, Chf. Engr, The Hagan Corporation; T. E. Purcell, Gen. Supt; Power Stations Dept, Duquesne Light Co; and the author.

A vote of thanks was extended to the author for his very interesting paper. The meeting adjourned at 10:20 P. M.

K. F. Treschow, *Secretary.*

REGULAR MONTHLY MEETING

The 435th regular monthly meeting of the Engineers' Society of Western Pennsylvania was held in the Blue Room, Wm. Penn Hotel, Tuesday, December 15th at 8:15 P. M., President Walter B. Spellmire presiding, 84 members and visitors being present.

The Minutes of the last regular meeting held Nov. 20th were read and approved.

The Board of Direction reported the election of four applicants to the grade of Member, three to the grade of Associate Member, one to the grade of Associate and one to the grade of Junior, and the receipt of 12 applications for membership. There were two reinstatements and one death reported.

No further business coming before the Society, the paper of the evening on "The Goedetic and Topographic Survey of Pittsburgh and Allegheny County" was presented by Messrs. U. N. Arthur, Chief Engineer and R. H. Randall, Engineer of Survey, Department of City Planning, City of Pittsburgh, Pittsburgh, Pa.

The ensuing discussion was participated in by: J. M. Rice, Consulting Engr, Pittsburgh; J. Hammond Smith, Professor, Civil Engineering, University of Pittsburgh; W. E. Fohl, Consulting Mining Engineer; Winters Haydock, Chf. Engr, Transit Commission, Pittsburgh, Pa; Webster Hinnau, Mgr. & Civil Engr, McCully Engineering Co; C. B. Stanton, Associate Professor, Civil Engineering, Carnegie Inst. of Technology; and the authors.

Mr. J. M. Rice presented a resolution to the effect that the Engineers' Society of Western Pennsylvania heartily approve the work now being done by the City and County in preparing an accurate topographic map and urges that both of these authorities be as generous in their appropriations for this work as consistent with the demands upon them for other purposes.

Motion seconded.

Mr. Fohl called attention to the fact that we have a Civic Affairs Committee and suggested that this matter be referred to them. It developed that in the case of the City, our time was very limited and the motion was, therefore, amended so that the Society write direct to the City and that the County be referred to the Civic Affairs Committee.

On motion the meeting adjourned at 10:00 P. M.

K. F. Treschow, *Secretary.*

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